TEST PLAN – COMPLETE GENERAL PROTUBERANCE HEAT TRANSFER TEST (U)

FEBRUARY 1964
DOUGLAS REPORT SM-46630

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1.0 INTRODUCTION

In the course of designing the Saturn stages, it was determined that placement of external protuberances on the stage was necessary to satisfy vehicle system requirements. These protuberances are generally either structural stiffeners of the hat or tee section type or aerodynamic fairings. The fairings protect vehicle subsystems from aerodynamic heating and excessive pressure buildup and reduce payload loss through excessive form drag. The protuberances are totally or partially immersed in the boundary layer, and the resulting interactions with the flow field about the stage and neighboring stringers or fairings create a complex flow pattern which cannot be adequately analyzed by available theory and empirical techniques. Thus, recourse to wind tunnel testing must be taken.

DAC presented the wind tunnel requirements for aerodynamic design of the S-IVB stage of MSFC in Report No. SM-42561. Included was a request for a program to evaluate the flow effects caused by protuberances on the vehicle skin and obtain information necessary for optimum protuberance design. MSFC requested a plan for a wind tunnel test program to obtain this information. Accordingly, SM-43625 which proposes a program to obtain aerodynamic force and heating data for S-IVB protuberances was submitted to MSFC.

After reviewing SM-43625, MSFC recommended an approach for evaluating protuberance parameters for Saturn design. General shapes, not exactly duplicating specific protuberance geometries, but having similar general characteristics are to be tested to obtain information on effects of protuberance forebody angle, afterbody angle, length, and height in relation to boundary layer height. Specific shapes are to be tested only for important design problems. Descriptions of actual Saturn program protuberances and comments were obtained from the following Saturn contractors: NAA-S&ID (S-II stage); Boeing (S-IC stage); Lockheed (S-N stage). MSC was contacted for possible Apollo protuberances, but no reply was received.

The General Protuberance Wind Tunnel Test program is the result of discussions and agreements between MSFC and DAC with inputs from the other stage contractors mentioned above. The program has been divided into three separate programs which are being conducted as follows:

(a) General Protuberance Force and Pressure Test conducted by DAC.

(b) General Protuberance Heat Transfer Test conducted by DAC.

(c) Acoustics Test integrated into NASA research studies.

The purpose of this report is to present the test plan for the General Protuberance Heat Transfer Test. This is being conducted as follows:

Mach number 2.5 - 4.5: Langley Unitary Plan Wind Tunnel, models designed and built at DAC.

Mach number 4.5 - 8.0: Cornell Aeronautical Laboratory 48-Inch Shock Tunnel, models designed at CAL and built at MSFC.

DAC will supply personnel to conduct and monitor these tests and will analyze the data and present it in a final report.

2.0 THE PROTUBERANCE HEAT TRANSFER PROBLEM

The thick turbulent boundary layer present over the external skin of the Saturn vehicle does not lend itself to analysis. Theoretical computation of boundary layer parameters is normally done assuming that the pressure gradient normal to the surface over which the boundary layer is flowing is constant ($\partial p / \partial y = 0$). This assumption simplifies integration of the equations of motion and is valid so long as the boundary layer is considered thin. The Saturn stages are large enough so that boundary layer thicknesses of several feet may be obtained at the aft end of the Saturn V. The external systems are often totally immersed in the boundary layer, and the resulting flow field is very complex.

At present, the only test data available and being used for design purposes come from a series of tests conducted by P. S. Yip of Convair in the Langley Unitary Plan Wind Tunnel. General geometric shapes and Atlas protuberances are included in this test. The Mach number range was approximately 2.5 to 4.5. The results of this test show that wide variations in heat transfer coefficient are experienced and that significant increases in the heat input to the vehicle skin in the vicinity of a protuberance will cause local hot spots. In some cases, entirely unanticipated large increases in heat transfer coefficient are observed. For example, in a gap immediately aft of a wedge and on the skin in front of a cylinder perpendicular to the vehicle skin.

In order to determine design heat transfer coefficients with acceptable accuracy, testing is necessary for Saturn protuberances. At present, the Yip data may be used for some cases, but an evaluation of the parameters involved for Saturn design is necessary.

3.0 TEST OBJECTIVES

The variations in aerodynamic heat transfer to the vehicle skin caused by protuberances and the aerodynamic heat transfer to the protuberances themselves will be studied. In order to obtain the necessary data, the best approach appears to be the same method that Yip used, that is, mounting an instrumented flat plate flush with the tunnel wall and mounting a protuberance on it. The vehicle boundary layer is simulated by the tunnel wall boundary layer and the test setup and assembly is designed to obtain the desired protuberance to boundary layer height relationship.

The effects of forebody angle, afterbody angle, body length, and ratio of protuberance height to boundary layer height on protuberance heat transfer will be investigated. Figure 1 shows the general shape to be used for this. It is representative of the type of fairing used on Saturn external systems. The general protuberance shapes shown in figure 2 are variations of this geometry. These configurations were chosen as having geometric characteristics similar to protuberances on all stages of Saturn.

There are some protuberances which may cause critical aerothermodynamic design problems. These are not amenable to simulation by the general shapes. For this reason, models of the S-IVB auxiliary propulsion system fairing and the S-II separation splice will be tested. (Interference effects between the engine shrouds and some smaller protuberances on the S-IC will be determined during the General Protuberance Force Test).

The experience in heat transfer testing gained by personnel at both facilities should be of considerable benefit in obtaining accurate results. The techniques to be used have produced useful data in previous tests.

4.0 LANGLEY UNITARY PLAN WIND TUNNEL TEST

4.1 Description of Test Facility

The investigation will be conducted in the high Mach number range test section of the Langley Unitary Plan Wind Tunnel. The design Mach number range is from 2.3 to 5.0 and the maximum stagnation pressure is approximately 150 psia. The continuous flow tunnel has an asymmetrical sliding block nozzle that permits variation in the test section Mach number while in operation. The working section or region for mounting the model is 4 feet wide and approximately 7 feet in length. Both stagnation pressure and stagnation temperature may be controlled independently. Other basic elements of the tunnel are the dry air supply and the cooling system.

4.2 Test Setup and Procedure

Since the purpose of the test is to investigate protuberances immersed in a turbulent boundary layer simulating the Saturn vehicle boundary layer, the laminated test plate will be mounted on the access door to the tunnel test section with the leading edge of the plate flush with the tunnel wall. The normal 6-inch tunnel test section boundary layer will provide the simulation. The ramp simulating the S-IVB / S-II interstage on the Saturn V will be mounted on the tunnel sting support system. The sting support will be traversed horizontally across the tunnel enabling the ramp to be placed at the aft end of the test plate during tunnel operation. The seven general protuberance models and the three models of specific shape will be mounted individually on the plate for testing (figure 3).

The test will be conducted using an increase in tunnel stagnation temperature. During normal tunnel operation using the tunnel cooling system, the stagnation temperature is approximately 120°F. By use of a large blade valve, the tunnel cooling system will be quickly bypassed allowing the tunnel stagnation temperature to increase at a rate of 16°F per second to about 240°F. The transient temperatures of thermocouples installed in the model surface will be recorded at 1/2 second intervals and the resulting temperature histories used to determine the heat transfer coefficients.

Each combination of the model, plate, and ramp will be run at Mach numbers of 2.5, 3.5, and 4.5. For test runs in which the model is yawed, the instrumented side of the model will be windward, also the stringers will be rotated on the test plate to the yawed position. Heat transfer coefficients will be obtained on the smooth test plate and ramp by removing the stringers and will be compared to values obtained by known theoretical means. The models to be used in the pressure runs will have their thermocouples replaced by pressure taps after being used in the heat transfer phase of the test. This will be done at the Langley facility. The boundary layer temperature rake will be used as needed to determine the temperature profile through the boundary layer.

4.2 (Cont'd.)

Temperature measurements on the models, stringers, test plate, and ramp will be obtained as a function of time by means of thermocouples. The thermocouples will be iron-constantan installed in 0.030 diameter holes in the model surface potted with pure tin. The Langley wind tunnel has the capability of recording 200 channels at 1/2 second intervals.

Pressure taps on the plate and ramp will be of 0.125 inch O. D. tubing. The locations of instrumentation on the models, plate, and ramp are given in table IV.

The boundary layer temperature rake will make use of temperature probes available at the Langley facility.

4.3 Description of Models

4.3.1 Test Plate

The test plate will be a flat laminated plate 60 inches long and 40.75 inches wide. It will consist of a 0.050 inch stainless steel test surface insulated by a 0.375 inch thick hexagonal fiberglas honeycomb bonded to a 0.125 inch stainless steel waffle back plate. Twenty removable stringers of phenolic fiberglas will be attached 2 inches between center lengthwise on the test surface. The stringers will be 0.5 inch by 0.5 inch cross-section with the leading and trailing faces having an angle of 30° with the plate surface. The plate will be placed in the boundary layer on the tunnel wall and mounted to the access door of the test section.

The plate will be instrumented with 123 thermocouples and 12 pressure orifices. The stringers will be instrumented with thermocouples in nine locations (figure 4).

4.3.2 Ramp

The ramp simulating the interstage between the S-IVB stage and the S-II stage of the Saturn V vehicle will be 6 inches in height and have an angle of 17° with the test plate (figure 5). The test surface of the ramp will be 34 inches wide and 20.5 inches in length. The ramp test surface will have the same construction as the test plate with 0.050 inch stainless steel test surface insulated with 0.375 inch fiberglas honeycomb bonded to 0.125 inch stainless steel waffle backing plate. There will be eighteen stringers on the ramp having the same cross section and at the same transverse location as the eighteen center stringers on the plate. These start 1 inch from the ramp leading edge. The leading and trailing faces of the stringers will have an angle of 30° with the ramp surface. The ramp will be mounted on the tunnel sting support to allow its removal without tunnel shutdown.

The ramp test surface will be instrumented with thirty-six thermocouples and seven pressure taps. Two of the stringers on the ramp will be instrumented with four thermocouples on each. To aid in determining the conduction losses through the test plate assembly, a thermocouple was placed between the stainless steel test surface and the honeycomb and one between the honeycomb and the waffle backing plate on the ramp.

4.3.3 Models

Of the thirteen models originally proposed, ten models have been recommended by Langley based on previous experience in protuberance heat transfer tests as configurations for which data are necessary. Seven of the protuberance models are general in shape and three represent protuberances of specific interest in reference to the designs used on the Saturn stages. For the general configurations the angle of the forebody and afterbody, body length, and height will be varied (figures 6 - 15).

Model Number	Forebody	Body	Afterbody
M_1	15°	2.5 CAL	15°
M_2	15°	2.5 CAL	30°
M_4	30°	1 CAL	30°
M_5	15°	2.5 CAL	0°
M_6	15°	0 CAL	15°
M_9 (1/2 No. 4)	30°	0.5 CAL	30°
M_{10} (2 No. 4)	30°	2 CAL	30°
M_{11} (S-IVB APS)			
M_{12} (S-II Separation Splice)			
M_{13} (Circumferential Ring Study)			

All of the models will be nickel electroformed shells 0.040 inch thick with a thick phenolic base for insulation with exception of the circumferential rings which will be phenolic fiberglas.

Models 1 and 4 will be used in runs to determine temperatures as well as runs to determine pressures. After use in the heat transfer phase, the thermocouples in the models will be drilled out and pressure taps will be installed in their place.

4.4 Run Schedule

The enclosed run schedule, table I, indicates the model, test plate, and ramp combinations to be tested and their corresponding yaw angle and wind tunnel Mach numbers. This is a summary run schedule and the actual order of the runs may differ to obtain a more satisfactory schedule for most efficient use of tunnel time.

5.0 CORNELL TEST

5.1 Description of Test Facility

The 48-inch hypersonic shock tunnel has a basic operating range of Mach 4.5 to 22, with real gas operating temperatures varying between 1300°R and 12000°R, and pressures between 10 and 300 atm.

The basic components of the tunnel are shown in figure 16. The tunnel employs a constant area shock tube 80 feet long and 8 inches in diameter to compress and heat the test air. The shock tube is separated into regions of high and low pressures by a diaphragm. The wave phenomena begins with the destruction of the diaphragm, permitting expansion of the high pressure driver gas into the low pressure air. The shock processed air at the end of the tube is then admitted to a nozzle and is expanded to the desired hypersonic test conditions. The nozzle employs removable throat inserts of various areas for Mach number variation.

The temperature of the air behind the shock in the driver section of the tube (corresponding to the reservoir or supply temperature in conventional wind tunnel terminology) is a function of the strength or velocity of the shock wave through the driver tube. If the stagnation temperature is to be duplicated at a given Mach number, the shock velocity or shock Mach number is then determined. The shock Mach number is, in turn, a function of the pressure ratio of the driver gas. In the CAL 48-inch tunnel, helium is used as the driver gas. Its velocity of sound is varied by mixing it with air to produce relatively weak shock waves and by heating it for strong shocks.

5.2 Test Setup and Procedure

It is presently planned to use a conical nozzle having a 10.5° semi-angle and a 24-inch exit diameter with various throat inserts to provide the desired test Mach numbers (4.5, 6.5, 8.0). The conical nozzle was selected over the contoured nozzle because it gives a more uniform flow pattern. There will be an increase of approximately 0.3 in test Mach number from the forward to the aft end of the test section, but this is not considered excessive. A splitter plate will be installed in the center of the nozzle with the heat transfer plate and ramp attached at the end of the splitter plate. The heat transfer plate, with the ramp, will be mounted flush with the end of the splitter plate to insure undisturbed flow upstream of the protuberance models. The heat transfer plate has the capability of being yawed 10° in the splitter plate plane. The models are instrumented on one side in order to pick up the windward heating effect when yawed. With the complete model set up; plate, model, and ramp (figure 17), there are eighty-seven thin-film sensors. The Cornell facility has the capability of recording only forty-four channels at one time.

It will therefore be necessary to make two runs on some configurations to get sufficient data and monitor all locations for which heat transfer measurement is necessary. Sensors on the model have been designated as primary or secondary sensors.

The measurement of heat transfer rates relies on sensing the transient surface temperature of the model and employs the thin film resistance thermometer. A typical gage consists of a thin film of platinum, approximately 0.1 micron thick by 5 mm by 0.5 mm, fused to a pyrex model insert. To insulate the metallic film from an ionized gas stream, a thin dielectric coating (magnesium fluoride) is deposited on the surface of the gage. As the heat capacity of the gage is negligible, the film temperature is a measure of the instantaneous surface temperature of the pyrex and is related to the heat transfer rate by the equation of heat transfer into an infinite slab of known thermal properties (reference 6). Analysis has shown this technique to be valid for 0.1 micron thick gages during the short duration of a shock tunnel test. The thin film gages have been used to measure heating rates as low as 0.3 BTU/ft^2-sec. By use of an analog network, the output proportional to surface temperature of the thin film gages may be converted directly to a voltage proportional to the heat transfer rate. Test results may thereby be monitored directly. The maximum instrumentation and recording errors are believed to total 10%.

The general protuberance modles will be instrumented with ten thin film sensors each. These sensors are located as indicated in figures 23 through 30. The flat plate and ramp sensor locations are indicated in figures 19 through 22.

Visual data will be recorded by means of high speed motion picture cameras using both color and black and white film. Schlieren photographs will also be taken.

5.3 Model Description

There are nine heat transfer models:

Model No.	Forebody	Body	Afterbody	Figure
M_1	15°	2.5 CAL	15°	23
M_2	15°	2.5 CAL	30°	24
M_4	30°	1.0 CAL	30°	25
M_5	15°	2.5 CAL	90°	26

Model No.	Forebody	Body	Afterbody	Figure
M_6	15°	0 CAL	15°	27
M_9	30°	0.5 CAL	30°	28
M_{10}	30°	2.0 CAL	30°	28
M_{11} (S-IVB APS)				29
M_{12} (Circumferential Ring Study)				30

Two flat plate configurations:

P_1	Plate with stringers	19
P_2	Plate without stringers	20

Two ramp configurations:

R_1	Ramp with stringers	21
R_2	Ramp without stringers	22

The complete setup, plate, ramp, and model are shown in figure 18.

The models will simulate the protuberances; the flat plate, the vehicle skin; and the ramp, the S-IVB - S-II interstage. The stringers represent the external stiffeners present on all stages of Saturn V. Models M_2 and M_4 are to be attached so either end may serve as forebody or afterbody. The circumferential rings (model M_9) represent external rings and flange joints on the S-N (RIFT) stage. They have the same cross section (0.15" x 0.15") as the stringers.

The models, plate, and ramp are to be built by NASA/MSFC and the instrumentation will be installed by CAL.

5.4 Run Schedule

Table I (runs 1-99) is the complete run schedule necessary for a comprehensive study of protuberance heating. The order of running is based on the most efficient use of time and does not reflect run priority.

Table II is an abbreviated run schedule which includes the runs necessary for a rough evaluation of protuberance heating effects over the test Mach number range. The results will be used to determine how much of the rest of the program is necessary to fulfill Saturn design data requirements after this part of the test is completed.

6.0 DATA ANALYSIS

The data will be analyzed at DAC for both tests. Final data will be presented in the same format used for the Yip results, this is, in plots showing lines of constant heat transfer coefficient. This will define the regions of protuberances and protuberance-induced heating effects.

One feature of the test is that data will be obtained at the same condition (Mach 4.5) by two completely different techniques (thin shell models instrumented with thermocouples at Langley, resistance thermometers at Cornell). Since accurate analytic methods are not available, this will be the only comparison available. Interpretation and verification of the test results should be enhanced by this.

In order to evaluate conduction losses through the sandwich plate assembly used in the Langley test, thermocouples have been installed between the honeycomb and the test plate and between the backing plate and the honeycomb. Corrections for conduction losses will be determined and applied to the results.

7.0 ADDITIONAL TEST INFORMATION

Questions regarding test scheduling, personnel, and administration should be directed to J. E. Vondette, A3-860, Ext. 2747.

Questions regarding test technical objectives and interpretation and analysis of data should be directed to S. C. Wilson, A3-863, Ext. 2750.

Questions regarding coordination with facilities may be directed to either of the above. The address where both may be reached is:

Douglas Aircraft Company, Inc.
Space Systems Center
5301 Bolsa Avenue
Huntington Beach, California

Telephone: 714-897-0311

The test is being coordinated at MSFC by Mr. E. Murphy, R-AERO-AT.

REFERENCES

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2. Anonymous, Description and Capabilities of the Cornell 48-inch Hypersonic Shock Tunnel, Cornell Aeronautical Lab., dated May, 1962.

3. Burbank, Paige B., Newlander, Robert A., and Collins, Ida K., Heat-Transfer and Pressure Measurements on a Flat-Plate Surface and Heat-Transfer Measurements on Attached Protuberances in a Supersonic Turbulent Boundary Layer at Mach Numbers of 2.65, 3.51, and 4.44, NASA TN D-1372, dated December, 1962.

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6. Vidal, R. J., Transient Surface Temperature Measurement, Cornell Aeronautical Lab. Report 114, dated March, 1962.

7. Yip, P. S., Test Reports for Phases I - IV of the Aerodynamic Heating Tests at the NASA Langley Unitary Plan Wind Tunnel, Convair Report Nos. ZT-7-020TN, ZT-7-025, ZT-7-027, and AE60-0175, dated August, 1958, May, 1959, July, 1959, and March, 1960.

TABLE I

RUN SCHEDULE FOR GENERAL PROTUBERANCE

HEAT TRANSFER TEST AT LANGLEY UNITARY PLAN WIND TUNNEL

RUN	CONFIGURATION	MACH NO.	YAW ANGLE (DEG)
1	P_1	2.5	0
2		3.5	
3		4.5	
4	$P_1 + R_1$	4.5	0
5		3.5	
6		2.5	
7	$P_1 + R_1 + M_1$	2.5	0
8		3.5	
9		4.5	
10	$P_1 + M_1$	4.5	0
11		3.5	
12		2.5	
13	$P_1 + M_4$	2.5	0
14		3.5	
15		4.5	
16	$P_1 + R_1 + M_4$	4.5	0
17		3.5	
18		2.5	
19	$P_1 + R_1 + M_2$	2.5	0
20		3.5	
21		4.5	
22	$P_1 + M_2$ Reversed	4.5	0
23		3.5	
24		2.5	
25	$P_1 + R_1 + M_2$ Reversed	2.5	0
26		3.5	
27		4.5	
28	$P_1 + R_1 + M_5$	4.5	0
29		3.5	
30		2.5	
31	$P_1 + M_5$ Reversed	2.5	0
32		3.5	
33		4.5	
34	$P_1 + M_6$	4.5	0
35		3.5	
36		2.5	
37	$P_1 + M_9$	2.5	0
38		3.5	
39		4.5	
40	$P_1 + M_{12}$	4.5	0
41		3.5	
42		2.5	
43	$P_1 + M_{10}$	2.5	0
44		3.5	
45		4.5	
46	$P_1 + R_1 + M_{11}$	4.5	0
47		3.5	
48		2.5	

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TABLE I (CONT'D.)

RUN	CONFIGURATION	MACH NO.	YAW ANGLE (DEG)
49	$P_1 + M_{13}$	2.5	0
50		3.5	
51		4.5	
52	P_3	4.5	0
53		3.5	
54		2.5	
55	$P_1 + M_2$	2.5	10
56		3.5	
57		4.5	
58	$P_1 + R_1$	4.5	10
59		3.5	
60		2.5	
61	P_2	2.5	0
62		3.5	
63		4.5	
64	$P_2 + R_2$	4.5	0
65		3.5	
66		2.5	
	PRESSURE RUNS		
67	$P_1 + R_1 + M_1$	2.5	0
68		3.5	
69		4.5	
70	$P_1 + R_1 + M_4$	4.5	0
71		3.5	
72		2.5	

MODEL NO.		FOREBODY	BODY	AFTERBODY
1		15^{o}	2.5 CAL	15^{o}
2		15^{o}	2.5 CAL	30^{o}
4		30^{o}	1 CAL	30^{o}
5		15^{o}	2.5 CAL	0^{o}
6		15^{o}	0 CAL	15^{o}
9	1/2 No. 4	30^{o}	0.5 CAL	30^{o}
10	2 No. 4	30^{o}	2 CAL	30^{o}
11	S-IVB APS			
12	S-II Separation Splice			
13	Circumferential Ring Study			

These will be used with:

P_1 Plate with stringers

P_2 Plate without stringers

R_1 Ramp with stringers

R_2 Ramp without stringers

P_3 P_1 with every other stringer removed

TABLE II

RUN SCHEDULE FOR GENERAL PROTUBERANCE

HEAT TRANSFER TEST AT CORNELL AERONAUTICAL LABORATORY

RUN NO.	CONFIGURATION	MACH NO.	YAW ANGLE (DEG)	SENSOR PICK-UP PLATE	SENSOR PICK-UP RAMP	SENSOR PICK-UP MODEL
1	P_1	4.5	0	Primary	0	0
2		6.5	0			
3		8.0	0			
4		8.0	0	Secondary	0	0
5		6.5	0			
6		4.5	0			
7	$P_1 + M_1$	4.5	0	Primary	0	Primary
8		6.5	0			
9		8.0	0			
10	$P_1 + M_2$ Reversed	8.0	0	Primary	0	Primary
11		6.5	0			
12		4.5	0			
13	$P_1 + M_4$	4.5	0	Primary	0	Primary
14		6.5	0			
15		8.0	0			
16		8.0	0	Secondary	0	0
17		6.5	0			
18		4.5	0			
19	$P_1 + M_5$ Reversed	4.5	0	Secondary	0	Primary
20		6.5	0			
21		8.0	0			
22		8.0	0	Primary	0	0
23		6.5	0			
24		4.5	0			
25	$P_1 + M_6$	4.5	0	Primary	0	Primary
26		6.5	0			
27		8.0	0			
28		8.0	0	Secondary	0	0
29		6.5	0			
30		4.5	0			

TABLE II (CONT'D.)

RUN SCHEDULE FOR GENERAL PROTUBERANCE

HEAT TRANSFER TEST AT CORNELL AERONAUTICAL LABORATORY

RUN NO.	CONFIGURATION	MACH NO.	YAW ANGLE (DEG)	SENSOR PICK-UP PLATE	SENSOR PICK-UP RAMP	SENSOR PICK-UP MODEL
31	$P_1 + M_9$	4.5	0	Secondary	0	Primary
32		6.5	0			
33		8.0	0			
34		8.0	0	Primary	0	0
35		6.5	0			
36		4.5	0			
37	$P_1 + M_{10}$	4.5	0	Primary	0	Primary
38		6.5	0			
39		8.0	0			
40		8.0	0	Secondary	0	0
41		6.5	0			
42		4.5	0			
43	$P_1 + M_{13}$	4.5	0	Primary	0	0
44		6.5	0			
45		8.0	0			
46	$P_1 + R_1$	8.0	0	Primary	0	0
47		6.5	0			
48		4.5	0			
49		4.5	0	Secondary	Secondary	0
50		6.5	0			
51		8.0	0			
52	$P_1 + R_1$	8.0	10	Secondary	Secondary	0
53		6.5	10			
54		4.5	10			
55		4.5	10	Primary	0	0
56		6.5	10			
57		8.0	10			
58	$P_1 + R_1 + M_1$	8.0	0	Secondary	Secondary	0
59		6.5	0			
60		4.5	0			
61	$P_1 + R_1 + M_2$	4.5	0	Secondary	Secondary	0
62		6.5	0			
63		8.0	0			
64		8.0	0	Primary	0	0
65		6.5	0			
66		4.5	0			

TABLE II (CONT'D.)

RUN SCHEDULE FOR GENERAL PROTUBERANCE

HEAT TRANSFER TEST AT CORNELL AERONAUTICAL LABORATORY

RUN NO.	CONFIGURATION	MACH NO.	YAW ANGLE (DEG)	SENSOR PICK-UP PLATE	SENSOR PICK-UP RAMP	SENSOR PICK-UP MODEL
67	$P_1 + R_1 + M_2$ Reversed	4.5	0	Secondary	Secondary	0
68		6.5	0			
69		8.0	0			
70	$P_1 + R_1 + M_4$	8.0	0	Secondary	Secondary	0
71		6.5	0			
72		4.5	0			
73		4.5	10	Secondary	Secondary	0
74		6.5	10			
75		8.0	10			
76		8.0	10	Primary	0	Primary
77		6.5	10			
78		4.5	10			
79	$P_1 + R_1 + M_5$	4.5	0	Primary	0	Primary
80		6.5	0			
81		8.0	0			
82		8.0	0	Secondary	Secondary	0
83		6.5	0			
84		4.5	0			
85	$P_1 + R_1 + M_{11}$	4.5	0	Secondary	Secondary	0
86		6.5	0			
87		8.0	0			
88		8.0	0	Primary	0	Primary
89		6.5	0			
90		4.5	0			
91	P_2	8.0	0	Primary	0	0
92		6.5	0			
93		4.5	0			
94	$P_2 + R_2$	4.5	0	Primary	Primary	0
95		6.5	0			
96		8.0	0			
97		8.0	10	Primary	Primary	0
98		6.5	10			
99		4.5	10			

DOUGLAS

TABLE III

SUPPLEMENTARY RUN SCHEDULE

CORNELL AERONAUTICAL LABORATORY

RUN NO.	CONFIGURATION	MACH NO.	YAW ANGLE (DEG)	SENSOR PICK-UP PLATE	SENSOR PICK-UP RAMP	SENSOR PICK-UP MODEL
1	P_2	4.5	0	Primary	0	0
2		6.5	0			
3		8.0	0			
4	$P_2 + R_2$	8.0	0	Primary	Primary	0
5		6.5	0			
6		4.5	0			
7	P_1	4.5	0	Primary	0	0
8		6.5	0			
9		8.0	0			
10		8.0	0	Secondary	0	0
11		6.5	0			
12		4.5	0			
13	$P_1 + M_5$ Reversed	4.5	0	Secondary	0	Primary
14		6.5	0			
15		8.0	0			
16		8.0	0	Primary	0	0
17		6.5	0			
18		4.5	0			
19	$P_1 + M_4$	4.5	0	Primary	0	0
20		6.5	0			
21		8.0	0			
22		8.0	0	Secondary	0	Primary
23		6.5	0			
24		4.5	0			
25	$P_1 + R_1 + M_4$	4.5	0	0	Secondary	Primary
26		6.5	0			
27		8.0	0			
28		8.0	10	0	Secondary	Primary
29		6.5	10			
30		4.5	10			
31		4.5	10	Primary	0	0
32		6.5	10			
33		8.0	10			

TABLE III (CONT'D.)

SUPPLEMENTARY RUN SCHEDULE

CORNELL AERONAUTICAL LABORATORY

MACH NO.	CONFIGURATION	MACH NO.	YAW ANGLE (DEG)	SENSOR PICK-UP PLATE	SENSOR PICK-UP RAMP	SENSOR PICK-UP MODEL
34	$P_1 + R_1$	8.0	0	Primary	0	0
35		6.5	0			
36		4.5	0			
37		4.5	0	0	Secondary	0
38		6.5	0			
39		8.0	0			
40	$P_1 + R_1 + M_{11}$	8.0	0	Secondary	Secondary	0
41		6.5	0			
42		4.5	0			
43		4.5	0	Primary	0	Primary
44		6.5	0			
45		8.0	0			

TABLE IV

LOCATION OF INSTRUMENTATION

THERMOCOUPLES

LANGLEY TEST

Model No. 1

No.	x	y	z
200	-18.5	0	2
201	-16.0	-1.2	1.5
202	-13.6	0	3.3
203	- 8.3	0	4.7
204	- 8.3	-2.1	2.9
205	- 8.3	-2.3	1.5
206	- 5.8	0	5.0
207	- 5.8	-2.3	3.1
208	- 5.8	-2.5	1.5
209	- 1.1	0	5.0
210	- 1.1	-2.3	3.1
211	- 1.1	-2.5	1.5
212	3.7	0	5.0
213	3.7	-2.3	3.1
214	3.7	-2.5	1.5
215	6.2	0	4.7
216	6.2	-2.1	2.9
217	6.2	-2.3	1.5
218	11.5	0	3.3
219	13.9	-1.1	1.5
220	16.3	0	2.0

Model No. 4

No.	x	y	z
400	-8.6	0	1.5
401	-6.5	-1.2	1.5
402	-6.0	0	2.9
403	-3.5	0	4.4
404	-3.5	-1.9	2.8
405	-3.5	-2.2	1.5
406	-1.5	0	5.0
407	-1.5	-2.3	3.2
408	-1.5	-2.5	1.5
409	1.5	0	5.0
410	1.5	-2.3	3.2
411	1.5	-2.5	1.5
412	3.5	0	4.4
413	3.5	-2.2	1.5
414	4.5	-1.7	2.4
415	6.6	0	2.6

Model No. 2

No.	x	y	z
300	-12.4	0	2.0
301	-10.0	-1.2	1.7
302	- 7.7	0	3.2
303	- 3.0	0	4.6
304	- 3.0	-2.1	2.9
305	- 3.0	-2.3	1.5
306	0.3	0	5.0
307	0.3	-2.3	3.1
308	0.3	-2.5	1.5
309	5.0	0	5.0
310	5.0	-2.3	3.1
311	5.0	-2.5	1.5
312	9.8	0	5.0
313	9.8	-2.5	1.5
314	12.8	0	4.1
315	12.8	-2.0	1.5
316	14.6	-1.4	1.9
317	16.4	0	1.9

Model No. 5

No.	x	y	z
500	-13.6	0	2.0
501	-11.2	-1.2	1.5
502	- 8.8	0	3.2
503	- 3.5	0	4.7
504	- 3.5	-2.0	2.9
505	- 3.5	-2.3	1.5
506	- 1.0	0	5.0
507	- 1.0	-2.4	3.1
508	- 1.0	-2.5	1.5
509	3.8	0	5.0
510	3.8	-2.4	3.1
511	3.8	-2.5	1.5
512	6.5	0	5.0
513	6.5	-2.4	3.1
514	6.5	-2.5	1.5
515	10.0	0	4.0
516	10.0	-1.3	1.5
517	10.0	0	1.5

TABLE IV (CONT'D.)

LOCATION OF INSTRUMENTATION

THERMOCOUPLES

LANGLEY TEST

Model No. 6

No.	x	y	z
600	-11.5	0	1.9
601	- 9.0	-1.0	1.5
602	- 6.5	0	3.2
603	- 1.5	0	4.6
604	- 1.5	-1.9	3.0
605	- 1.5	-2.3	1.5
606	1.5	0	4.6
607	1.5	-1.9	3.0
608	1.5	-2.3	1.5
609	6.5	0	3.2
610	9.0	-1.0	1.5
611	11.5	0	1.9

Model No. 9

No.	x	y	z
700	- 3.8	0	1.0
701	- 2.8	-0.8	0.8
702	- 1.8	0	2.2
703	- 1.8	-0.8	1.4
704	- 1.8	-1.0	0.8
705	- 0.8	0	2.5
706	- 0.8	-1.0	1.5
707	- 0.8	-1.2	0.8
708	0.7	0	2.5
709	0.7	-1.0	1.5
710	0.7	-1.2	0.8
711	1.7	0	2.2
712	1.7	-0.8	1.4
713	1.7	-1.0	0.8
714	2.7	-0.8	0.8
715	3.7	0	1.0

Model No. 10

No.	x	y	z
800	-14.5	0	4.5
801	-10.6	-3.1	4.2
802	- 6.6	0	9.1
803	- 6.6	-4.1	5.6
804	- 6.6	-4.5	1.5
805	- 3.5	0	10.0

Model No. 10 (cont.)

No.	x	y	z
806	-3.5	-4.7	6.7
807	-3.5	-5.0	1.5
808	3.5	0	10.0
809	3.5	-4.7	6.7
810	3.5	-5.0	1.5
811	6.5	0	9.1
812	6.5	-4.1	5.6
813	6.5	-4.5	1.5
814	10.6	-3.1	4.2
815	14.5	0	4.5

Model No. 11

No.	x	y	z
900	-7.9	0	2.0
901	-6.7	-4.1	1.6
902	-6.7	-3.5	0.6
903	-3.6	0	4.5
904	-0.1	0	6.5
905	0.1	-7.2	5.6
906	0.7	-8.3	3.5
907	0.7	-5.7	0.6
908	3.1	0	7.4
909	6.2	0	7.4
910	6.2	-7.9	6.4
911	6.2	-8.9	4.0
912	6.2	-6.3	0.6
913	9.4	0	7.4
914	14.5	-3.5	7.4
915	16.2	0	9.0
916	16.2	-8.9	4.0
917	16.2	-6.3	0.6

Model No. 12

No.	x	y	z
950	-2.3	0	0.1
951	-1.7	0	0.3
952	-1.1	0	0.4
953	-0.6	0	0.6
954	-0.1	0	0.6
955	0.6	0	0.4

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TABLE IV (CONT'D.)

LOCATION OF INSTRUMENTATION

THERMOCOUPLES

LANGLEY TEST

Model No. 12 (Cont.)

No.	x	y	z
956	1.1	0	0.3
957	1.7	0	0.1
958	-1.1	2.0	0.4
959	-0.6	2.0	0.6
960	-2.3	-0.5	0.1
961	-1.7	-0.5	0.3
962	-1.1	-0.5	0.4
963	-0.6	-0.5	0.6
964	-0.6	-1.0	0.6
965	-0.1	-0.5	0.6
966	-0.1	-1.0	0.6
967	1.7	-0.5	0.1

Test Plate

No.	x	y
1	-29.0	0
2	-28.0	0
3	-27.0	0
4	-26.0	0
5	-25.0	0
6	-24.0	0
7	-23.0	0
8	-22.0	0
9	-21.0	0
10	-20.0	0
11	-19.0	0
12	-18.0	0
13	-17.0	0
14	-16.0	0
15	-15.0	0
16	-14.0	0
17	-13.0	0
18	-12.0	0
19	-11.0	0
20	-10.0	0
21	- 9.0	0
22	- 8.0	0
23	- 7.0	0
24	- 6.0	0
25	- 5.0	0
26	- 4.0	0
27	- 3.6	0

Test Plate (Cont.)

No.	x	y
28	-3.3	0
29	3.5	0
30	4.0	0
31	5.0	0
32	6.0	0
33	7.0	0
34	8.0	0
35	9.0	0
36	10.0	0
37	11.0	0
38	12.0	0
39	13.0	0
40	14.0	0
41	15.0	0
42	16.0	0
43	17.0	0
44	18.0	0
45	19.0	0
46	20.0	0
47	21.0	0
48	22.0	0
49	23.0	0
50	24.0	0
51	25.0	0
52	26.0	0
53	27.0	0
54	-28.3	2.0
55	-24.5	2.0
56	-24.5	4.0
57	-24.5	6.0
58	-24.5	8.0
59	-24.5	10.0
60	-24.5	14.0
61	-19.5	2.0
62	-19.5	4.0
63	-19.5	6.0
64	-19.0	10.0
65	-17.0	4.0
66	-17.0	10.0
67	-15.0	2.0
68	-15.0	4.0
69	-15.0	6.0
70	-15.0	8.0
71	-15.0	10.0
72	-15.0	12.0

TABLE IV (CONT'D.)

LOCATION OF INSTRUMENTATION

THERMOCOUPLES

LANGLEY TEST

Test Plate (Cont.)

No.	x	y
73	-15.0	16.0
74	-13.0	4.0
75	-13.0	10.0
76	-11.0	2.0
77	-11.0	4.0
78	-11.0	10.0
79	- 9.0	4.0
80	- 9.0	10.0
81	- 7.0	4.0
82	- 7.0	10.0
83	- 5.0	2.0
84	- 5.0	4.0
85	- 5.0	6.0
86	- 5.0	8.0
87	- 5.0	10.0
88	- 5.0	12.0
89	- 5.0	14.0
90	- 5.0	16.0
91	0.0	4.0
92	0.0	10.0
93	5.0	2.0
94	5.0	4.0
95	5.0	6.0
96	5.0	8.0
97	5.0	10.0
98	5.0	12.0
99	5.0	14.0
100	5.0	16.0
101	10.0	2.0
102	10.0	10.0
103	15.0	2.0
104	15.0	4.0
105	15.0	6.0
106	15.0	10.0
107	15.0	14.0
108	20.0	2.0
109	20.0	10.0
110	25.0	2.0
111	25.0	4.0
112	25.0	6.0
113	25.0	8.0
114	25.0	10.0
115	25.0	12.0
116	25.0	14.0
117	-24.5	-6.0

Test Plate (Cont.)

No.	x	y
118	-18.8	-10.0
119	-15.0	- 6.0
120	- 7.0	-10.0
121	- 5.0	-10.0
122	10.0	-10.0
123	20.0	-10.0

Ramp

No.	x′	y	z′
150	4.3	0	0
151	4.9	0	0
152	7.2	0	0
153	9.4	0	0
154	11.7	0	0
155	14.0	0	0
156	16.3	0	0
157	17.5	0	0
158	4.9	2.0	0
159	4.9	6.0	0
160	4.9	10.0	0
161	4.9	12.0	0
162	9.4	2.0	0
163	9.4	4.0	0
164	9.4	6.0	0
165	9.4	8.0	0
166	9.4	10.0	0
167	9.4	12.0	0
168	11.3	8.0	0
169	13.8	8.0	0
170	16.3	2.0	0
171	16.3	4.0	0
172	16.3	6.0	0
173	16.3	8.0	0
174	16.3	10.0	0
175	16.3	12.0	0
176	4.9	-6.0	0
177	9.4	-6.0	0
190	8.4	-2.0	-0.1
191	8.4	-2.0	-0.5

TABLE IV (CONT'D.)

LOCATION OF INSTRUMENTATION

THERMOCOUPLES

LANGLEY TEST

Stringers (Plate)

No.	x	y	z
130	-15.1	6.8	0.3
131	- 5.75	3.0	0.5
132	- 5.1	7.0	0.5
133	4.25	3.2	0.3
134	4.9	7.2	0.3
135	14.25	2.8	0.3
136	-19.4	-1.0	0.5
137	-16.2	-1.2	0.3
138	-13.1	-0.8	0.3

Stringers (Ramp)

No.	x′	y	z′
180	5.0	7.0	0.5
181	7.0	6.8	0.3
182	9.5	7.2	0.3
183	11.7	7.0	0.5
184	5.0	-1.0	0.5
185	7.0	-1.2	0.3
186	9.5	-0.8	0.3
187	11.7	-1.0	0.5

Boundary Layer Rake

No.	z
140	0.2
141	1.2
142	2.2
143	3.2
144	4.2
145	5.2

TABLE IV (CONT'D.)

LOCATION OF INSTRUMENTATION

PRESSURE TAPS

LANGLEY TEST

Model No. 1

No.	x	y	z
P200	-18.5	0	2
P201	-16.0	-1.2	1.5
P202	-13.6	0	3.3
P203	- 8.3	0	4.7
P204	- 8.3	-2.1	2.9
P205	- 8.3	-2.3	1.5
P206	- 5.8	0	5.0
P207	- 5.8	-2.3	3.1
P208	- 5.8	-2.5	1.5
P209	- 1.1	0	5.0
P210	- 1.1	-2.3	3.1
P211	- 1.1	-2.5	1.5
P212	3.7	0	5.0
P213	3.7	-2.3	3.1
P214	3.7	-2.5	1.5
P215	6.2	0	4.7
P216	6.2	-2.1	2.9
P217	6.2	-2.3	1.5
P219	13.9	-1.1	1.5
P220	16.3	0	2.0

Model No. 4

No.	x	y	z
P400	-8.6	0	1.5
P401	-6.5	-1.2	1.5
P402	-6.0	0	2.9
P403	-3.5	0	4.4
P404	-3.5	-1.9	2.8
P405	-3.5	-2.2	1.5
P406	-1.5	0	5.0
P407	-1.5	-2.3	3.2
P408	-1.5	-2.5	1.5
P409	1.5	0	5.0
P410	1.5	-2.3	3.2
P411	1.5	-2.5	1.5
P412	3.5	0	4.4
P413	3.5	-2.2	1.5
P414	4.5	-1.7	2.4
P415	6.6	0	2.6

Test Plate

No.	x	y
P1	-24.3	-4.0
P2	-19.5	-4.0
P3	-19.5	-8.0
P4	-12.7	-4.0
P5	- 5.0	-4.0
P6	- 5.0	-8.0
P7	- 5.0	-12.0
P8	0	-4.0
P9	5.0	-4.0
P10	15.0	-4.0
P11	25.0	-4.0
P12	25.0	-8.0

Ramp

No.	x	y
P13	4.9	-4.0
P14	9.4	-4.0
P15	9.4	-10.0
P16	9.4	-14.0
P17	16.3	-4.0
P18	16.3	-10.0
P19	16.3	-14.0

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TABLE V

LOCATION OF INSTRUMENTATION

CORNELL TEST

TEST PLATE - WITH STRINGERS

GAGE NO.	X (IN.)	Y (IN.)	GAGE NO.	X (IN.)	Y (IN.)
1	-8.625	.0	30	1.875	.0
2	-7.875	.0	31	1.875	1.200
3	-7.125	.0	32	1.875	1.800
4	-7.125	.600	33	1.875	2.400
5	-7.125	1.200	34	1.875	3.000
6	-7.125	1.800	35	1.875	3.600
7	-6.375	.0	36	2.625	.0
8	-5.625	.0	37	3.375	.0
9	-5.625	1.200	38	3.375	1.200
10	-4.875	.0	39	4.125	.0
11	-4.125	.0	40	4.125	.600
12	-4.125	.600	41	4.125	1.200
13	-4.125	1.200	42	4.125	1.800
14	-4.125	1.800	43	4.125	2.400
15	-3.375	.0	44	4.125	3.000
16	-2.625	.0	45	4.875	.0
17	-2.625	.600	46	5.625	.0
18	-2.625	1.200	47	5.625	1.200
19	-1.875	.0	48	5.625	2.400
20	-1.125	.600	49	5.625	3.000
21	-1.125	1.200	50	6.375	.0
22	-1.125	1.800	51	7.125	.0
23	-1.125	2.400	52	7.875	.0
24	- .375	1.200	53	7.875	1.200
25	.375	1.200	54	7.875	1.800
26	.375	1.800	55	7.875	2.400
27	.375	2.400	56	7.875	3.000
28	.375	3.000	57	8.625	.0
29	1.125	.600			

NOTE: SEE FIGURE 19 FOR DESCRIPTION OF COORDINATE SYSTEM.

TABLE V (CONT'D.)

LOCATION OF INSTRUMENTATION

CORNELL TEST

PLATE WITHOUT STRINGERS

GAGE NO.	X (IN.)	Y (IN.)
78	-8.625	.0
79	-7.125	.0
80	-7.125	.600
81	-7.125	1.200
82	-7.125	1.800
83	-5.625	.0
84	-4.125	.0
85	-4.125	1.200
86	-2.625	.0
87	1.875	.0
88	1.875	1.200
89	1.875	2.400
90	1.875	3.600
91	3.375	.0
92	4.875	.0
93	6.375	.0
94	7.875	.0
95	7.875	1.800
96	7.875	3.000

RAMP WITHOUT STRINGERS

GAGE NO.	X (IN.)	Y (IN.)
97	.750	.0
98	.750	1.200
99	2.250	.0
100	2.250	2.400
101	2.250	4.800
102	3.750	.0
103	6.000	.0
104	9.000	.0
105	9.000	2.400
106	9.000	4.800
107	12.000	.0

TABLE V (CONT'D.)

LOCATION OF INSTRUMENTATION

CORNELL TEST

TEST RAMP - WITH STRINGERS

GAGE NO.	X (IN.)	Y (IN.)
58	.750	.0
59	.750	1.200
60	1.500	.0
61	2.250	.0
62	2.250	.600
63	2.250	1.200
64	2.250	1.800
65	2.250	2.400
66	3.000	.0
67	3.750	.0
68	4.500	.0
69	6.000	.0
70	7.500	.0
71	9.000	.0
72	9.000	1.200
73	9.000	2.400
74	9.000	3.600
75	9.000	4.800
76	10.500	.0
77	12.000	.0

NOTE: SEE FIGURE 21 FOR DESCRIPTION OF COORDINATE SYSTEM.

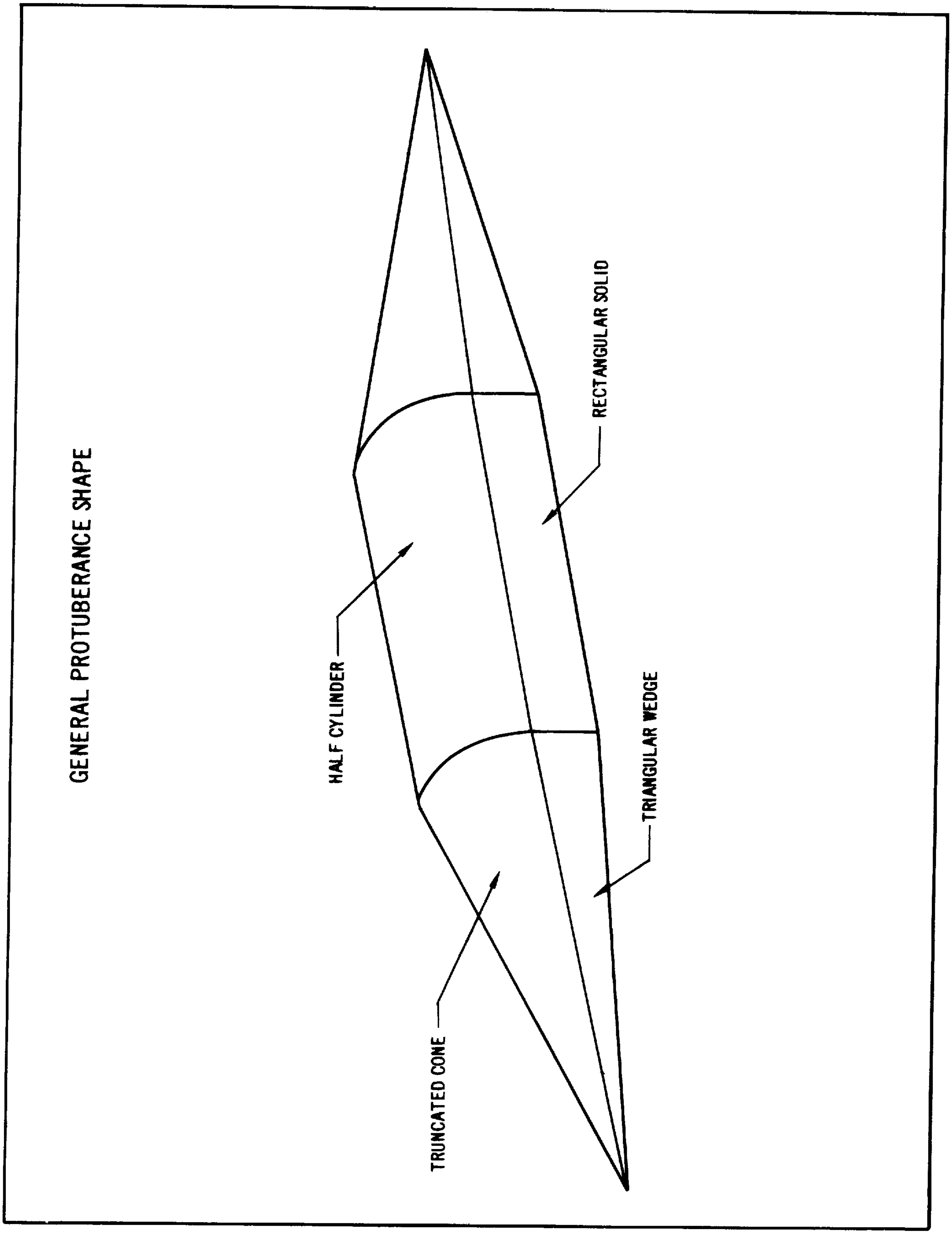

GENERAL PROTUBERANCE SHAPE
RECTANGULAR SOLID
HALF CYLINDER
TRIANGULAR WEDGE
TRUNCATED CONE

FIGURE 1

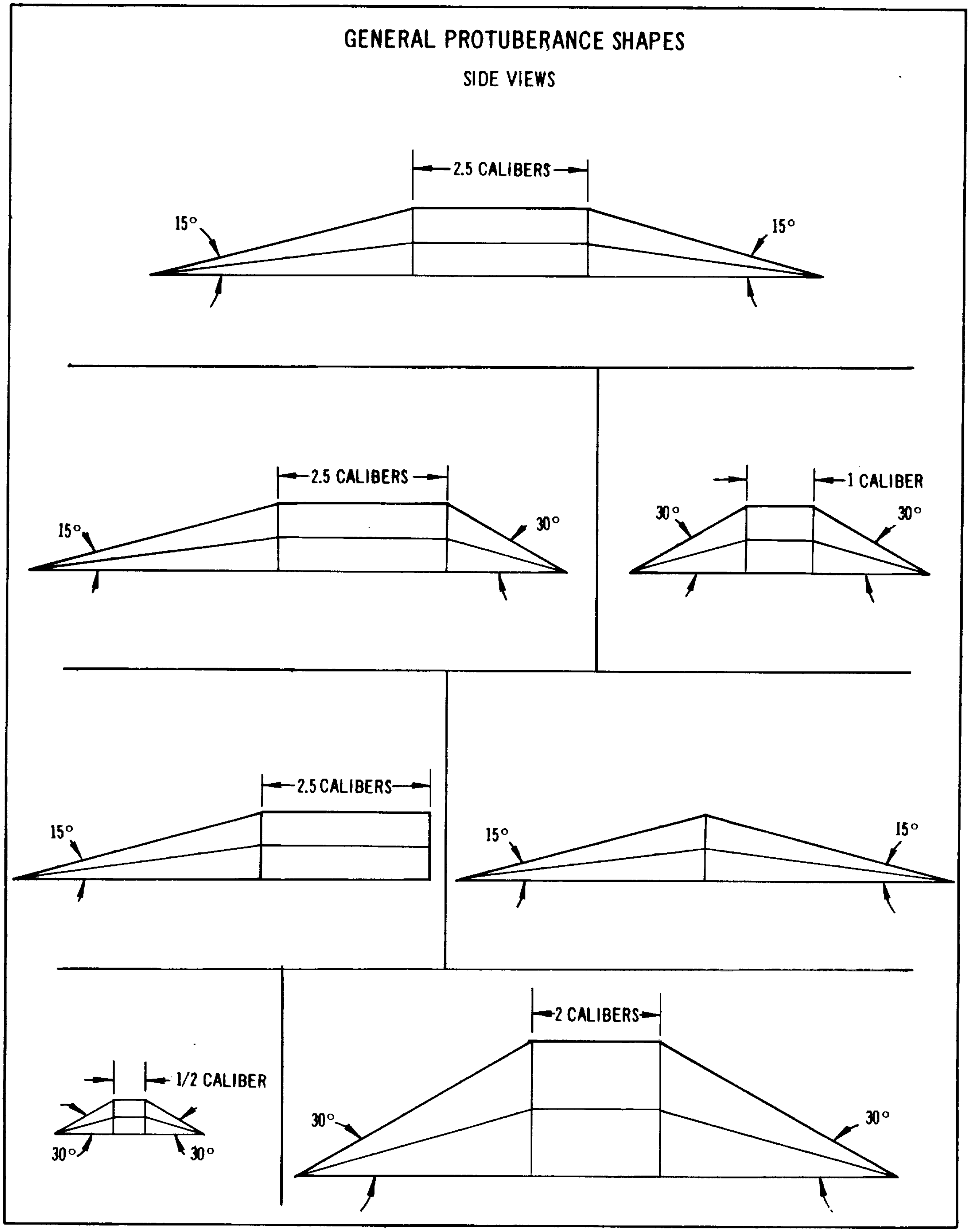

GENERAL PROTUBERANCE SHAPES
SIDE VIEWS
2.5 CALIBERS
15°
15°
2.5 CALIBERS
15°
30°
1 CALIBER
30°
30°
2.5 CALIBERS
15°
15°
15°
1/2 CALIBER
30°
30°
2 CALIBERS
30°
30°

FIGURE 2

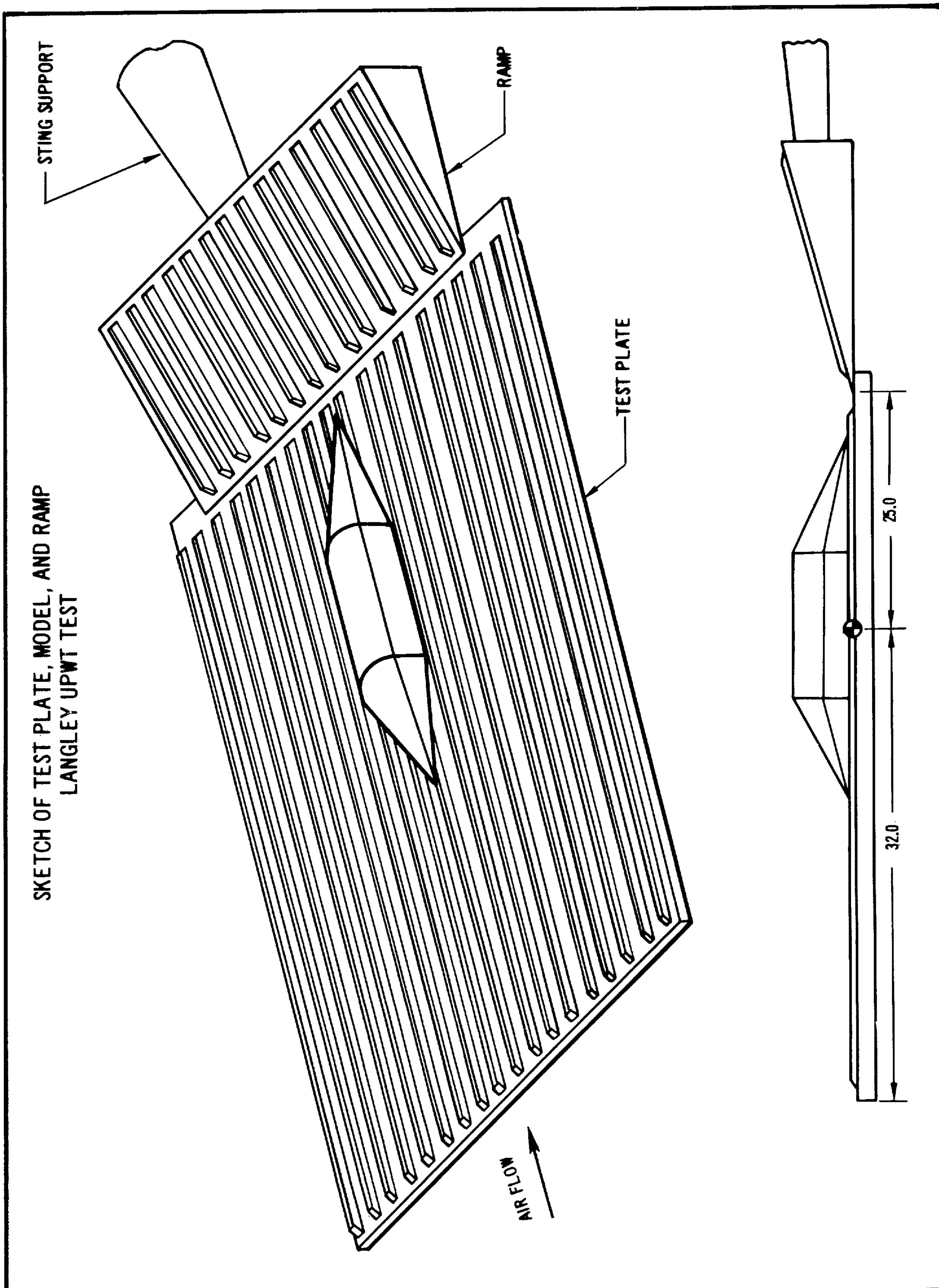

SKETCH OF TEST PLATE, MODEL, AND RAMP
LANGLEY UPWT TEST
STING SUPPORT
RAMP
TEST PLATE
AIR FLOW
25.0
32.0

FIGURE 3

TEST PLATE
LANGLEY UPWT TEST

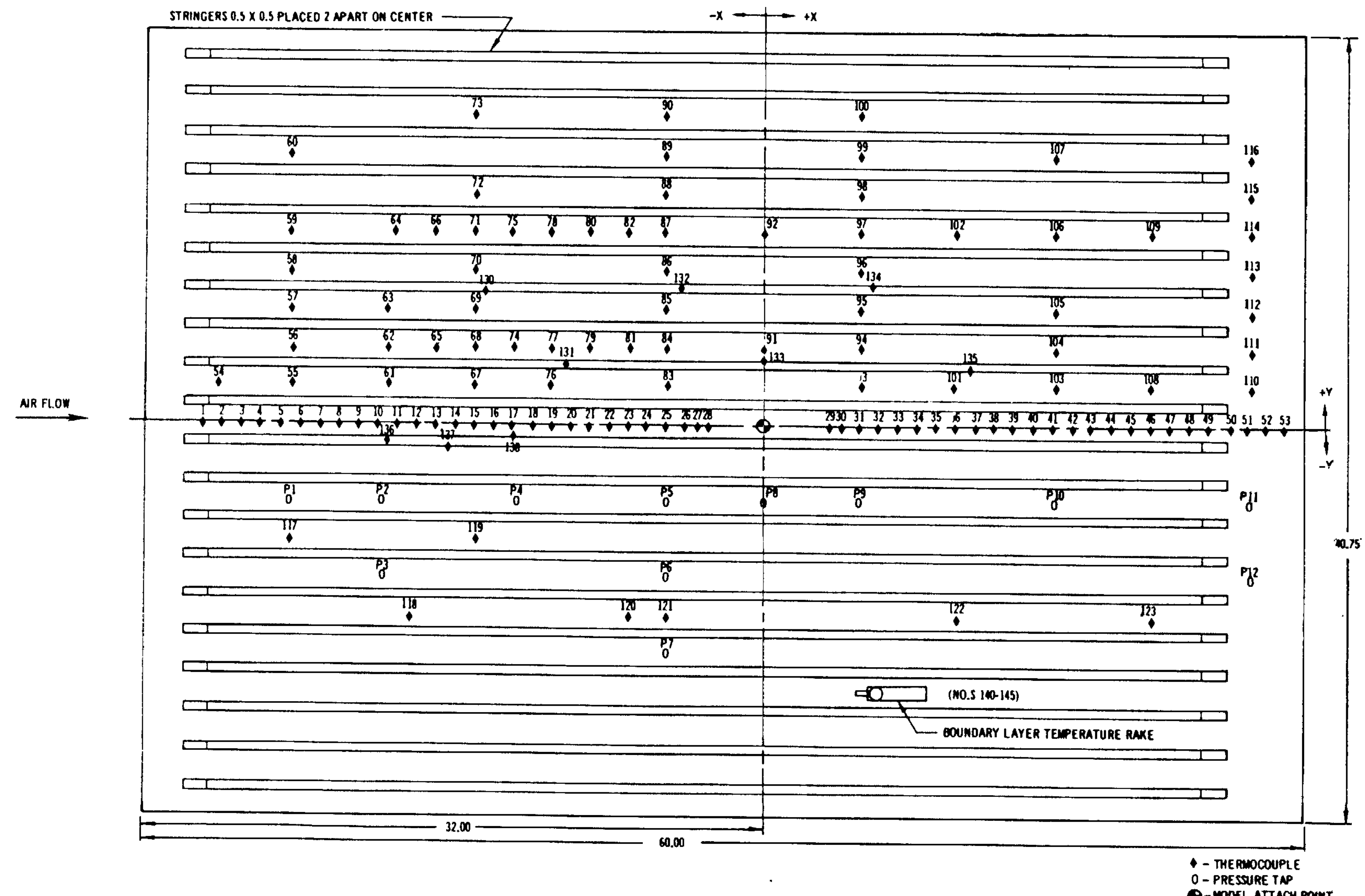


FIGURE 4

RAMP
LANGLEY UPWT TEST

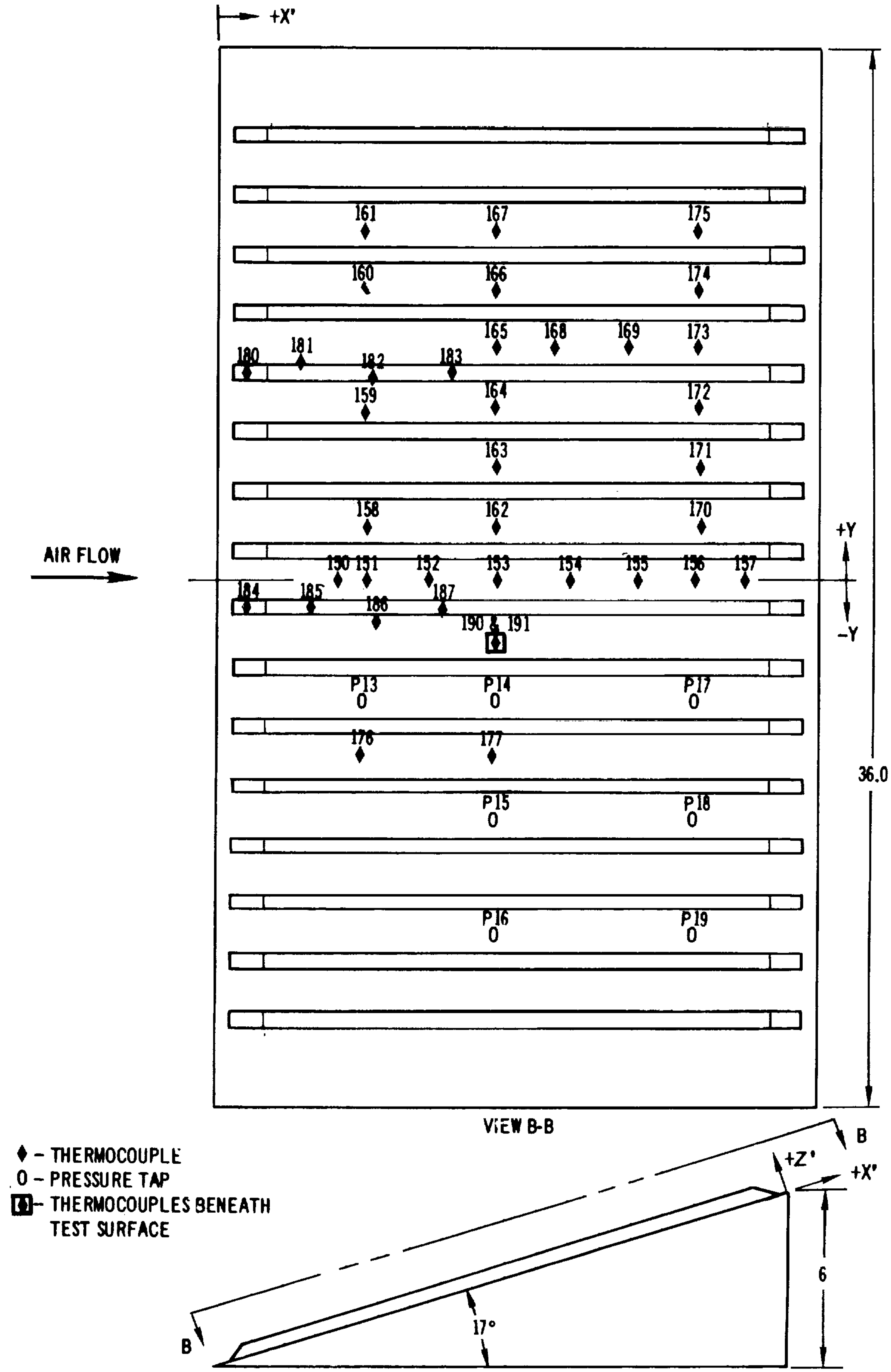


FIGURE 5

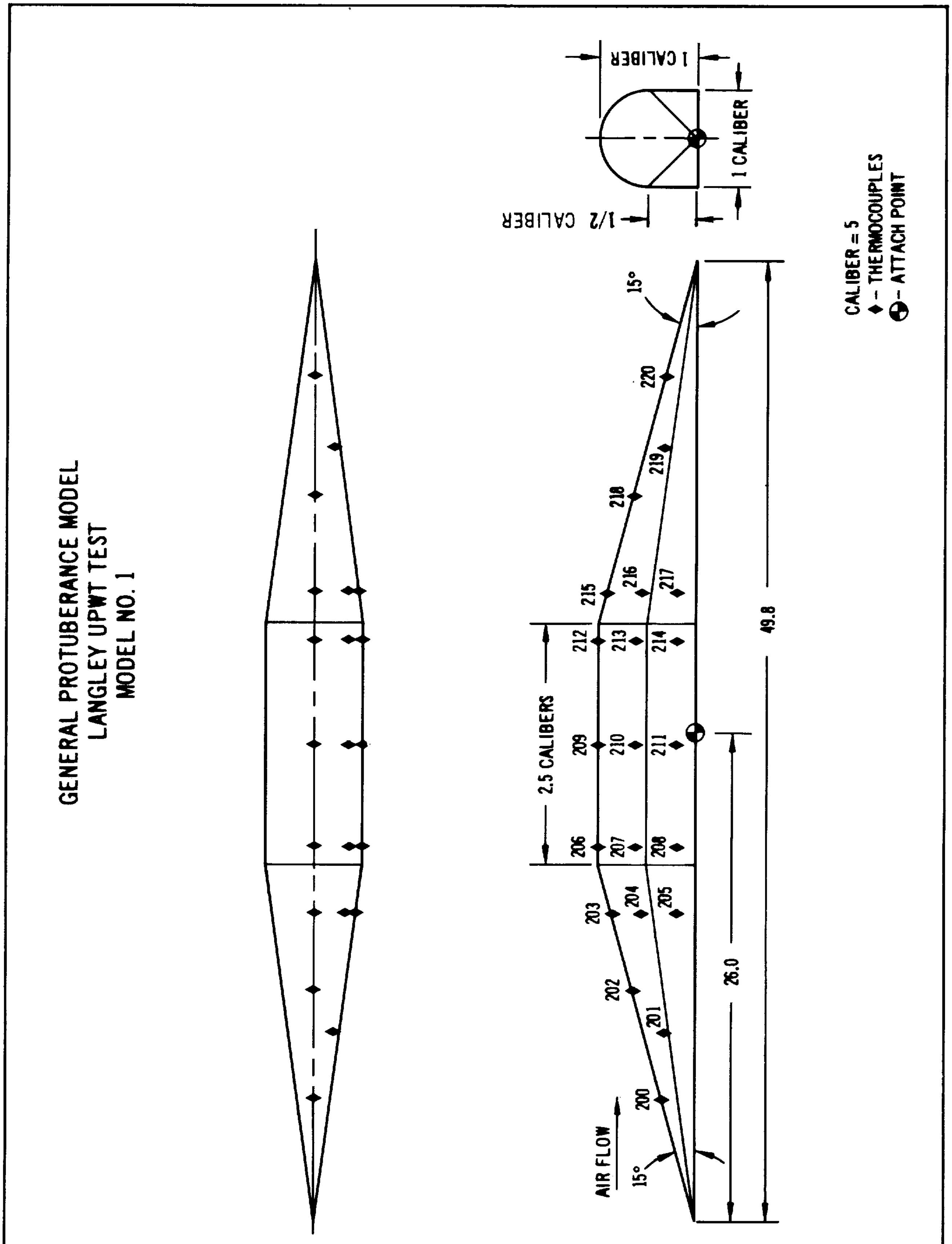

GENERAL PROTUBERANCE MODEL
LANGLEY UPWT TEST
MODEL NO. 1
1 CALIBER
1 CALIBER
1/2 CALIBER
CALIBER = 5
- THERMOCOUPLES
- ATTACH POINT
15°
15°
AIR FLOW
2.5 CALIBERS
49.8
26.0
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220

FIGURE 6

SM 46630

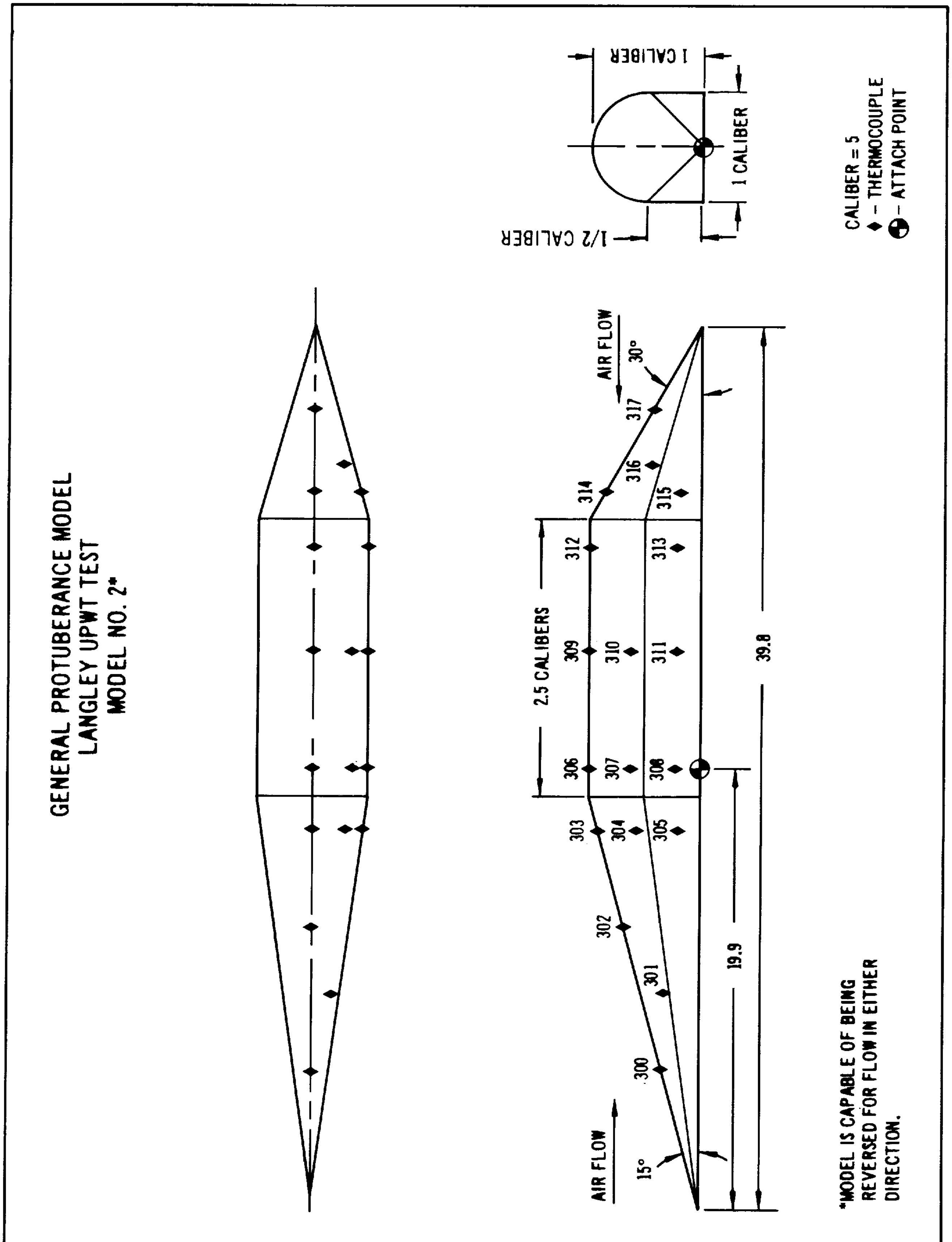


FIGURE 7

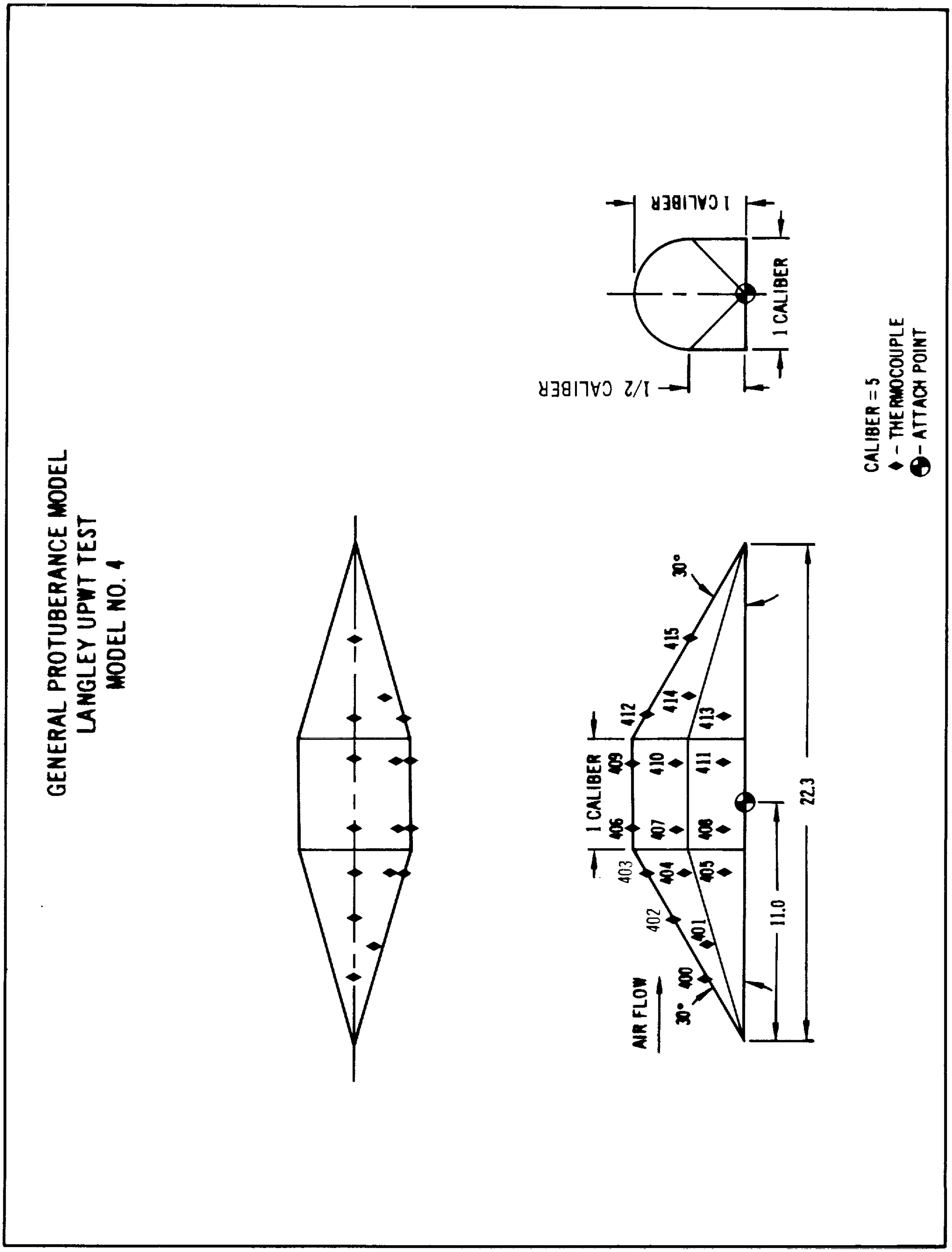

GENERAL PROTUBERANCE MODEL
LANGLEY UPWT TEST
MODEL NO. 4
AIR FLOW
30°
30°
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
1 CALIBER
11.0
22.3
1/2 CALIBER
1 CALIBER
1 CALIBER
CALIBER = 5
THERMOCOUPLE
ATTACH POINT

FIGURE 8

SM 46630

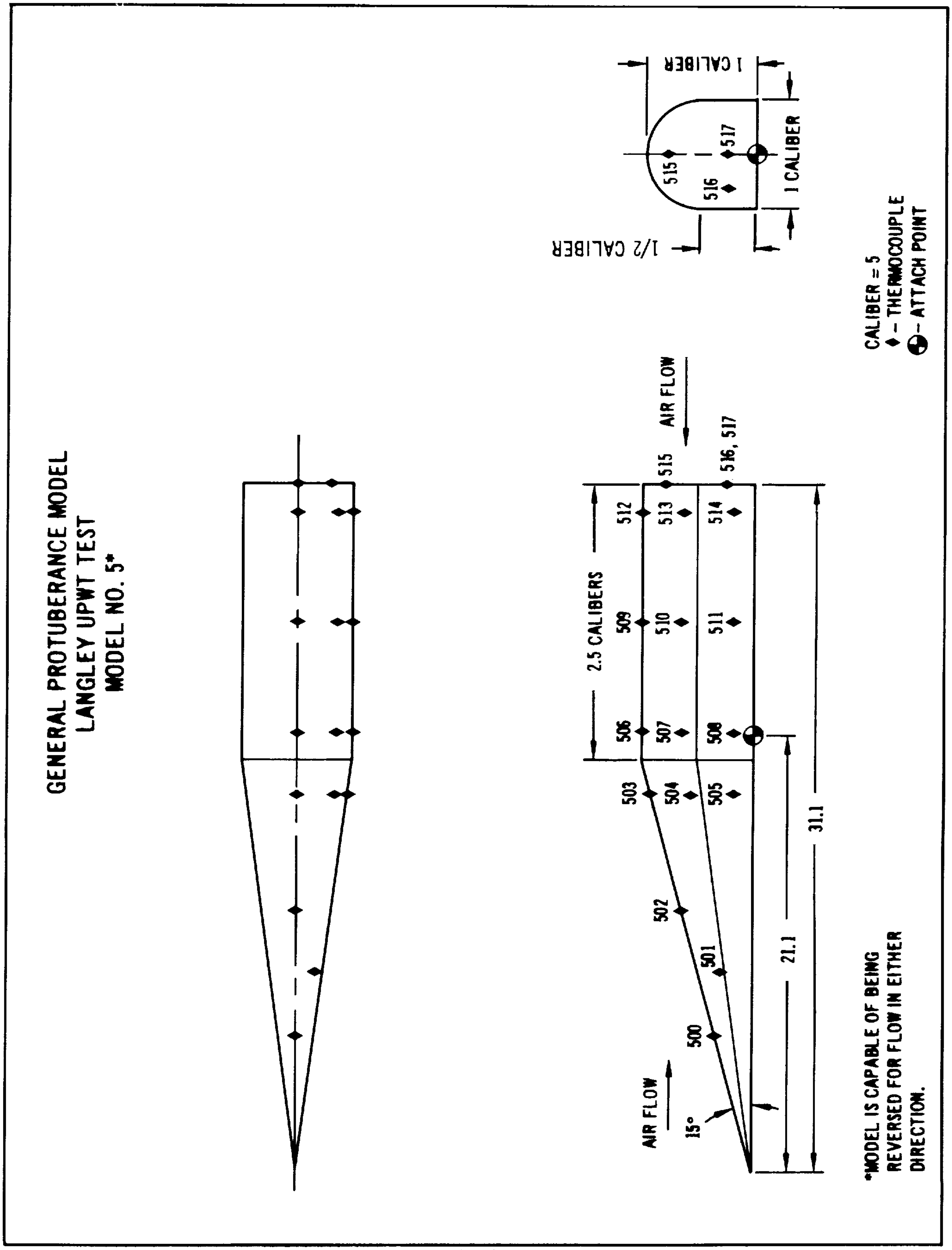


FIGURE 9

SM 46630

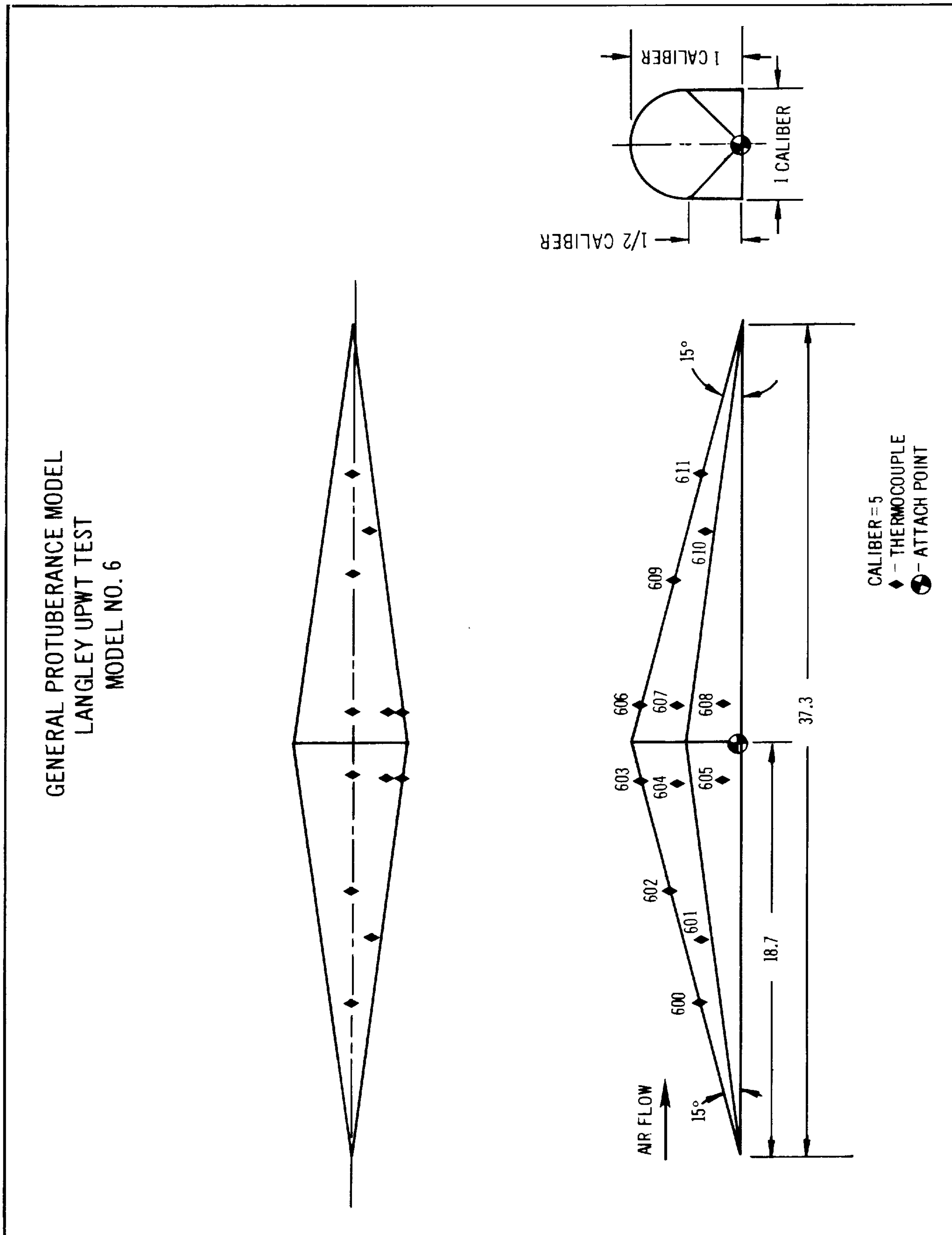
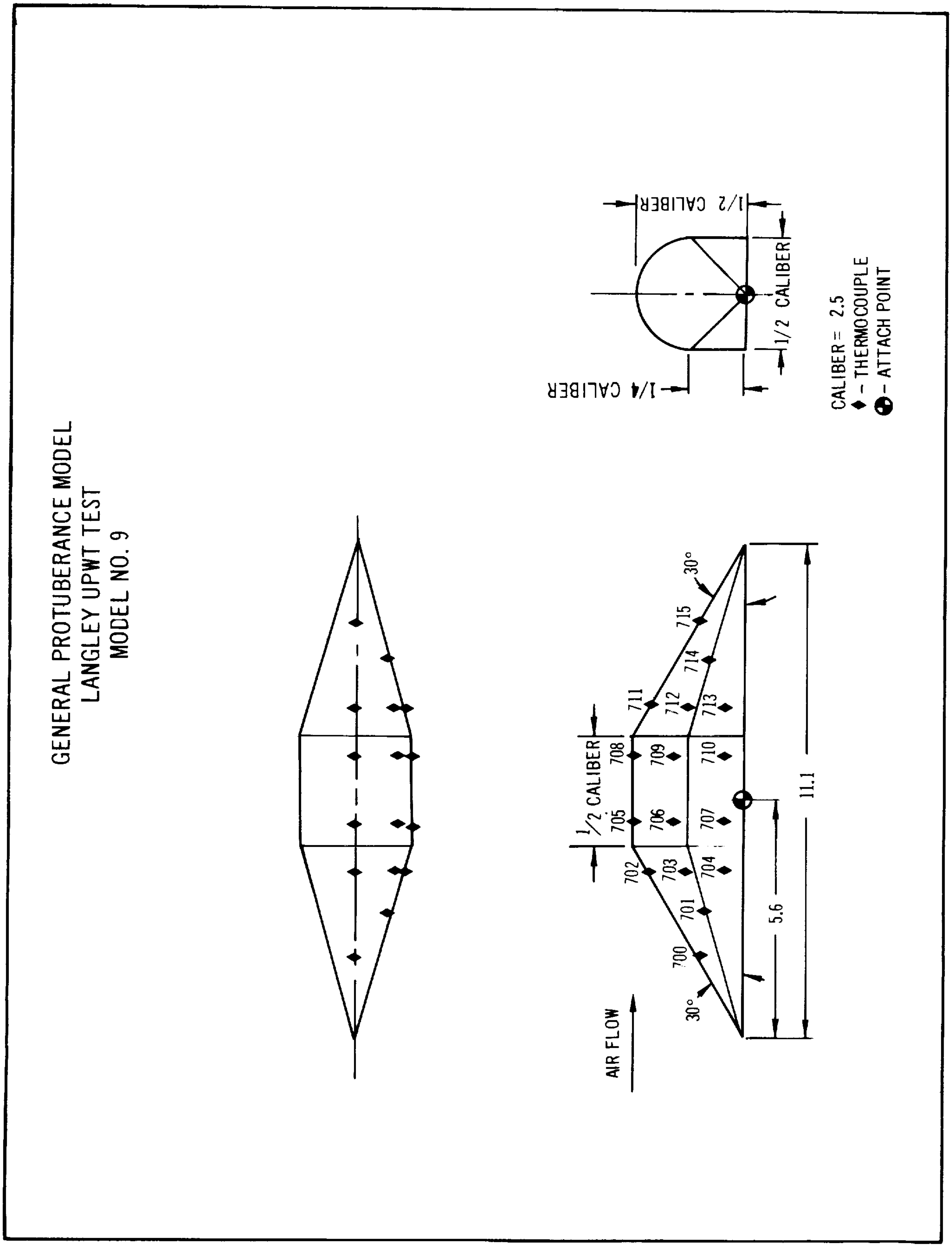


FIGURE 10



GENERAL PROTUBERANCE MODEL
LANGLEY UPWT TEST
MODEL NO. 9
AIR FLOW
30°
700
701
702
703
704
1/2 CALIBER
705
706
707
708
709
710
711
712
713
714
715
30°
5.6
11.1
1/4 CALIBER
1/2 CALIBER
1/2 CALIBER
CALIBER = 2.5
- THERMOCOUPLE
- ATTACH POINT

FIGURE 11

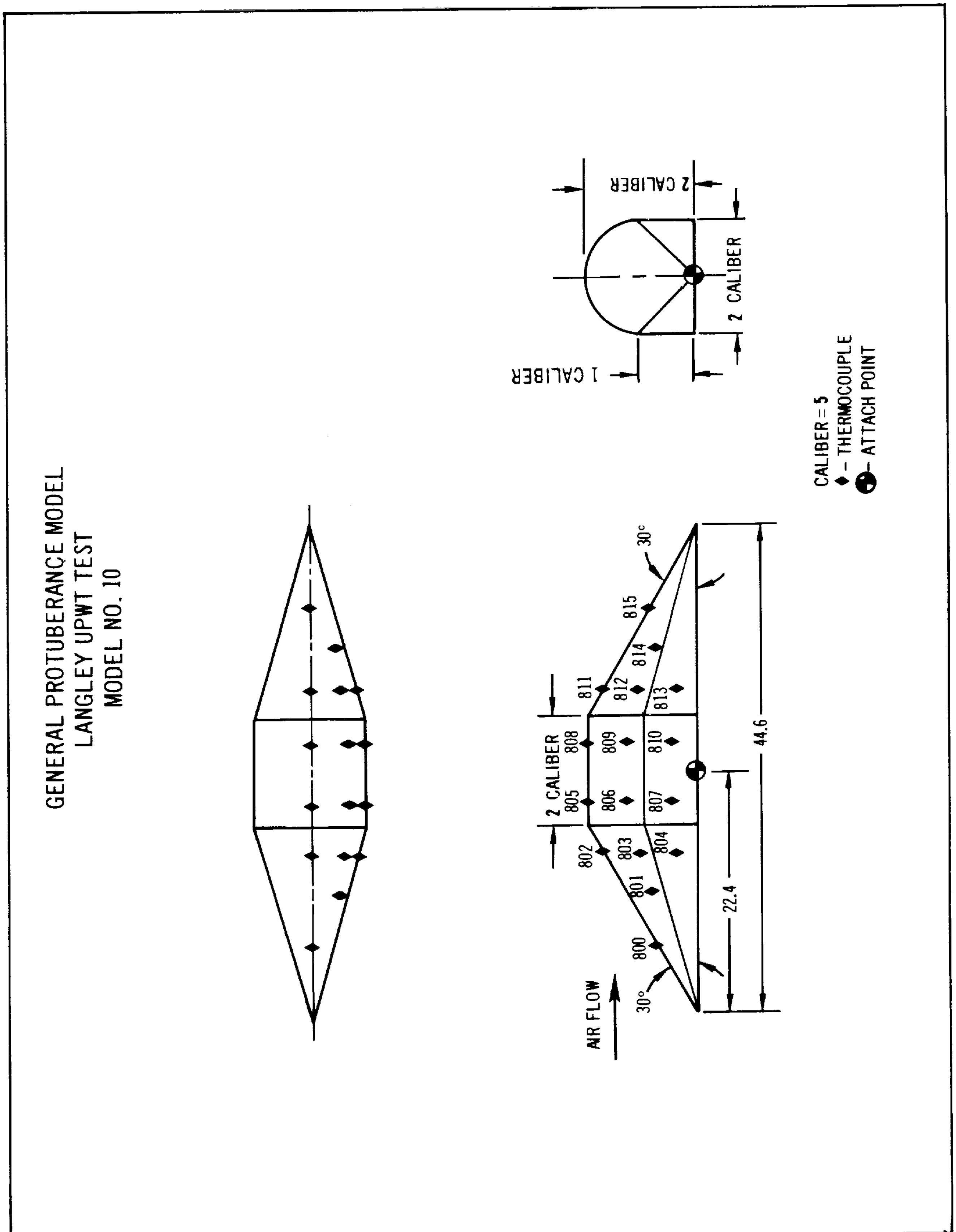

GENERAL PROTUBERANCE MODEL
LANGLEY UPWT TEST
MODEL NO. 10
2 CALIBER
1 CALIBER
2 CALIBER
CALIBER = 5
- THERMOCOUPLE
- ATTACH POINT
AIR FLOW
30°
30°
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
2 CALIBER
22.4
44.6

FIGURE 12

AUXILIARY PROPULSION SYSTEM
(SATURN V/S-IVB)
LANGLEY UPWT TEST
MODEL NO. 11

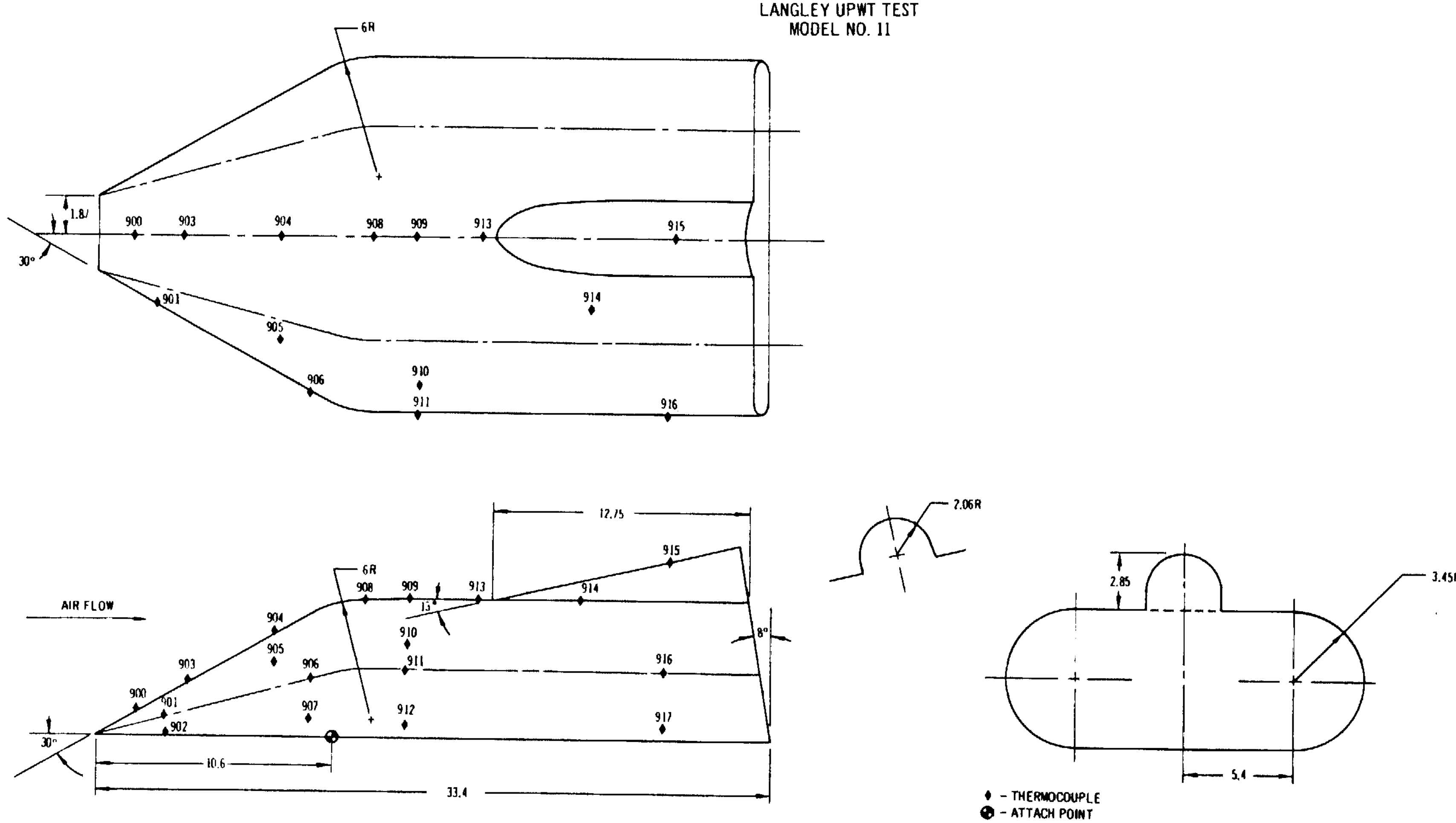


FIGURE 13

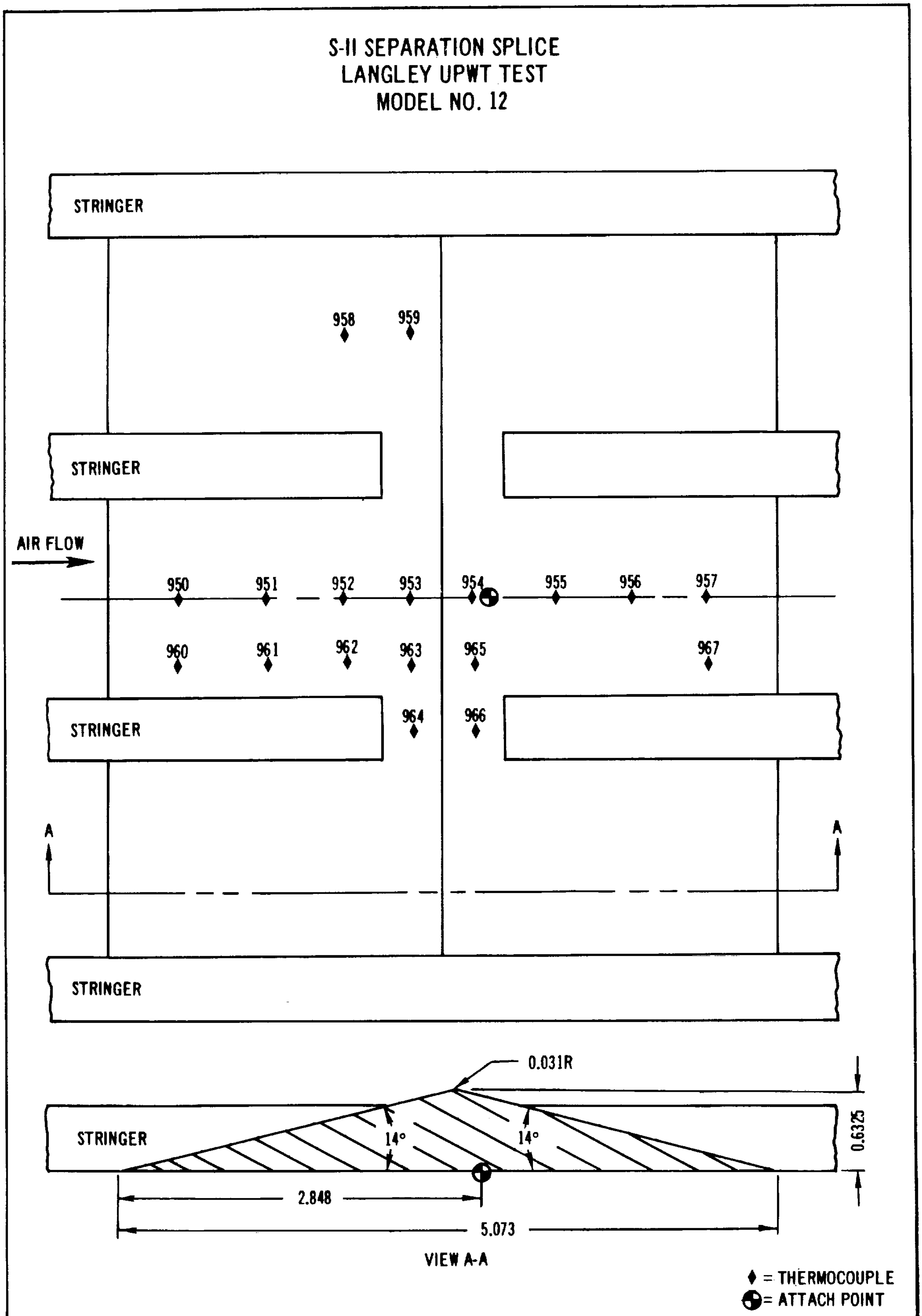

S-II SEPARATION SPLICE
LANGLEY UPWT TEST
MODEL NO. 12
STRINGER
958
959
STRINGER
AIR FLOW
950
951
952
953
954
955
956
957
960
961
962
963
965
967
STRINGER
964
966
A
A
STRINGER
0.031R
STRINGER
14°
14°
0.6325
2.848
5.073
VIEW A-A
= THERMOCOUPLE
= ATTACH POINT

FIGURE 14

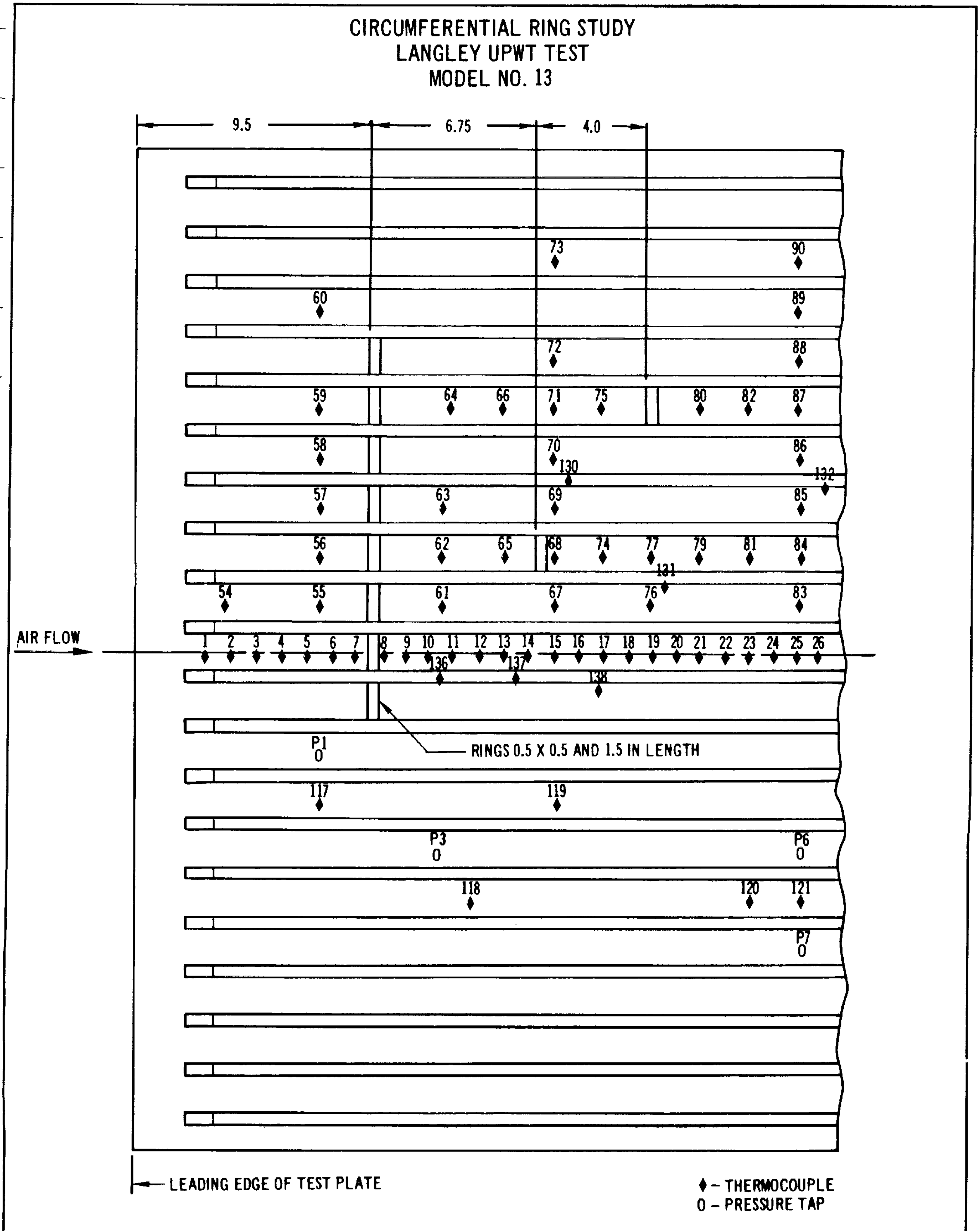

CIRCUMFERENTIAL RING STUDY
LANGLEY UPWT TEST
MODEL NO. 13
9.5
6.75
4.0
AIR FLOW
RINGS 0.5 X 0.5 AND 1.5 IN LENGTH
LEADING EDGE OF TEST PLATE
♦ – THERMOCOUPLE
0 – PRESSURE TAP

FIGURE 15

SM 46630

BASIC COMPONENTS OF THE CORNELL AERONAUTICAL LABORATORY 48" HYPERSONIC SHOCK TUNNEL

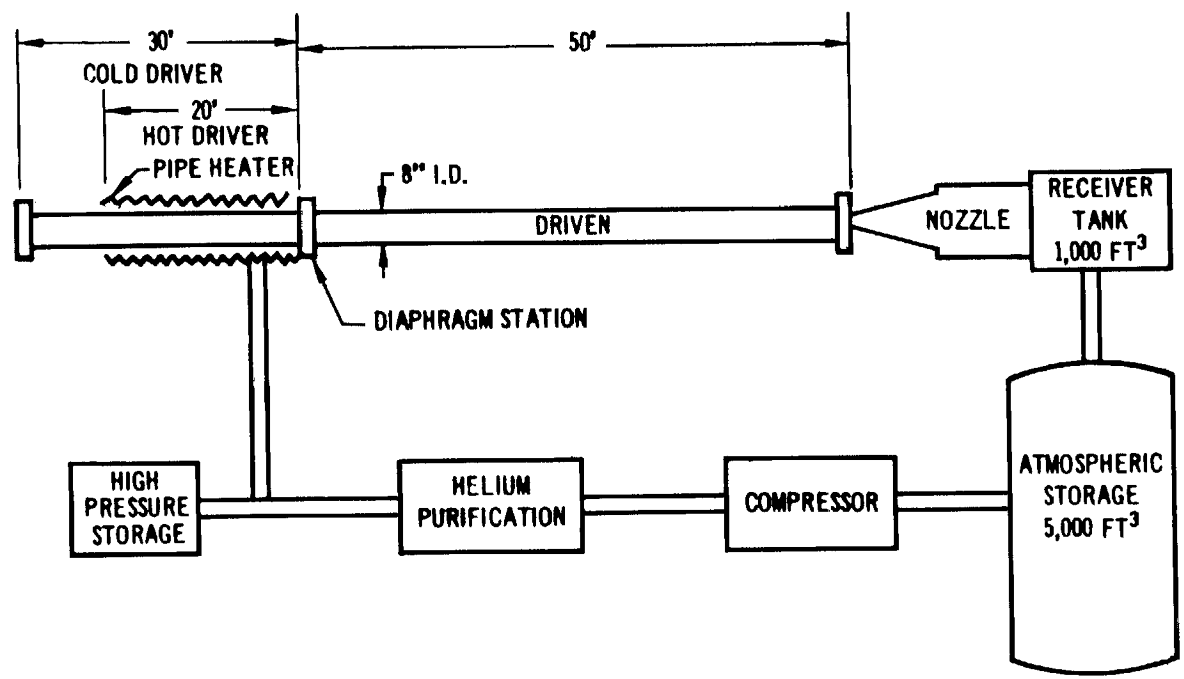
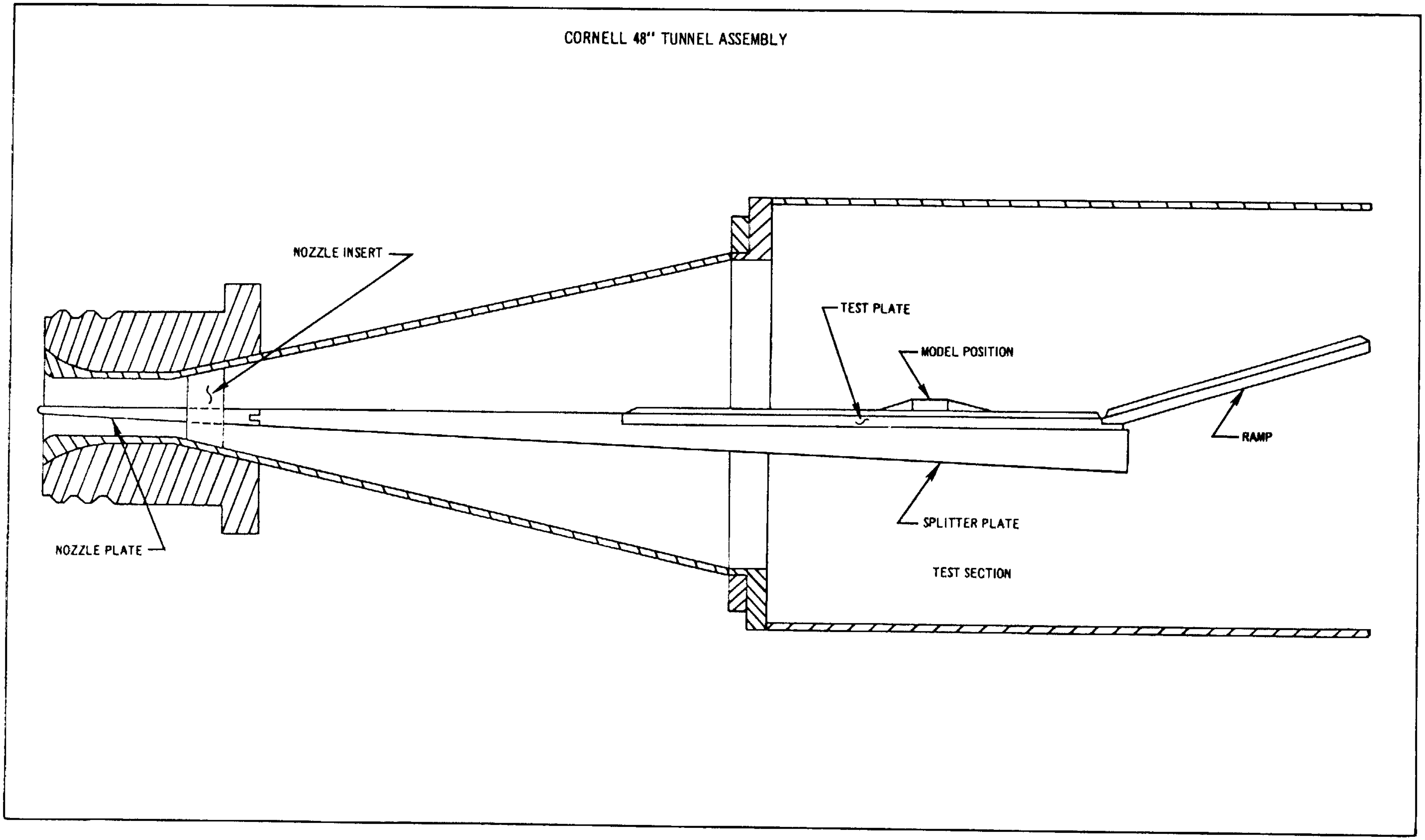


FIGURE 16



CORNELL 48" TUNNEL ASSEMBLY
NOZZLE INSERT
NOZZLE PLATE
TEST PLATE
MODEL POSITION
RAMP
SPLITTER PLATE
TEST SECTION

FIGURE 17

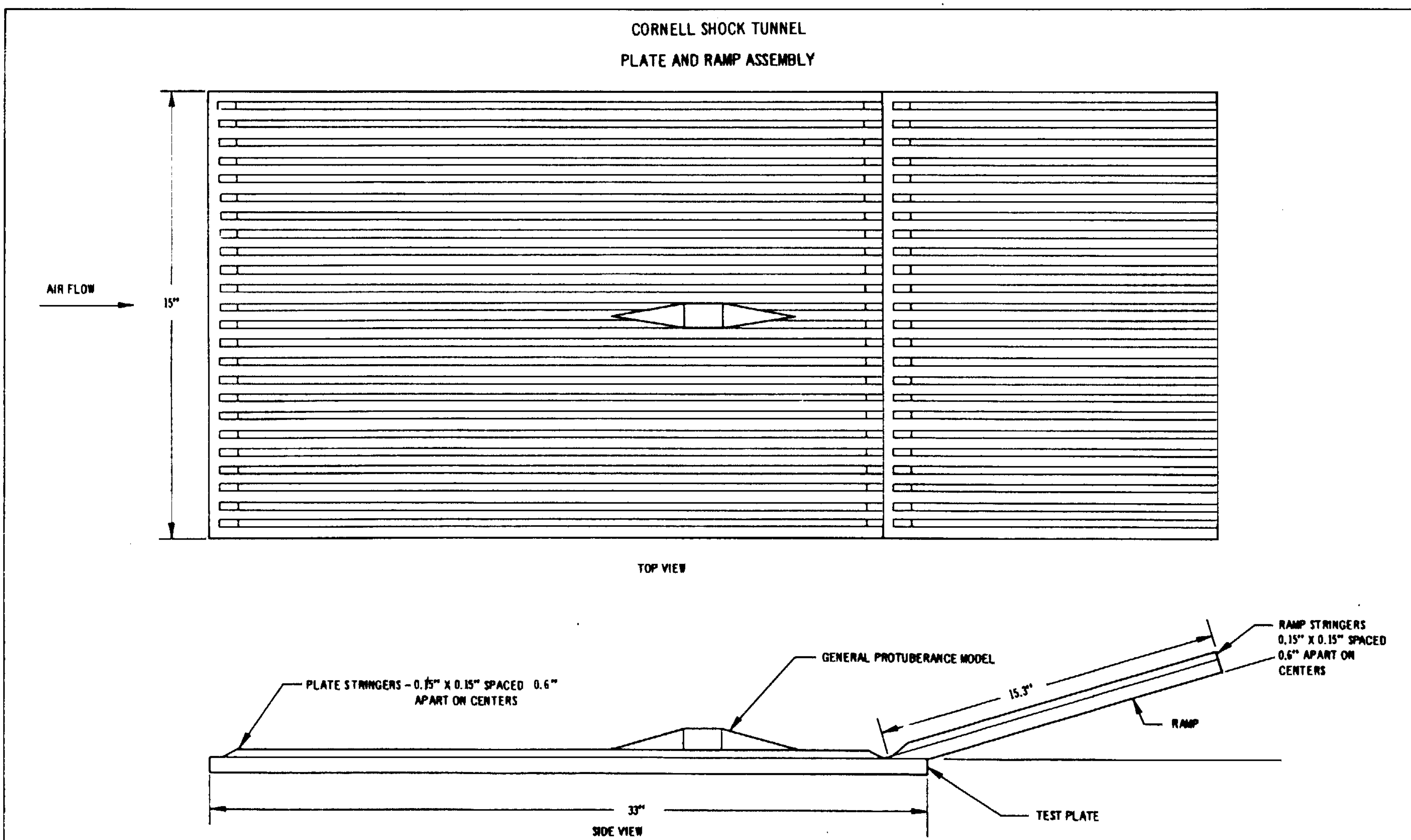

CORNELL SHOCK TUNNEL
PLATE AND RAMP ASSEMBLY
AIR FLOW
15"
TOP VIEW
PLATE STRINGERS - 0.15" X 0.15" SPACED 0.6" APART ON CENTERS
GENERAL PROTUBERANCE MODEL
15.3"
RAMP STRINGERS 0.15" X 0.15" SPACED 0.6" APART ON CENTERS
RAMP
33"
SIDE VIEW
TEST PLATE

FIGURE 18

HEAT TRANSFER TEST PLATE WITH STRINGERS
CORNELL SHOCK TUNNEL
TEMPERATURE GAGE LOCATIONS

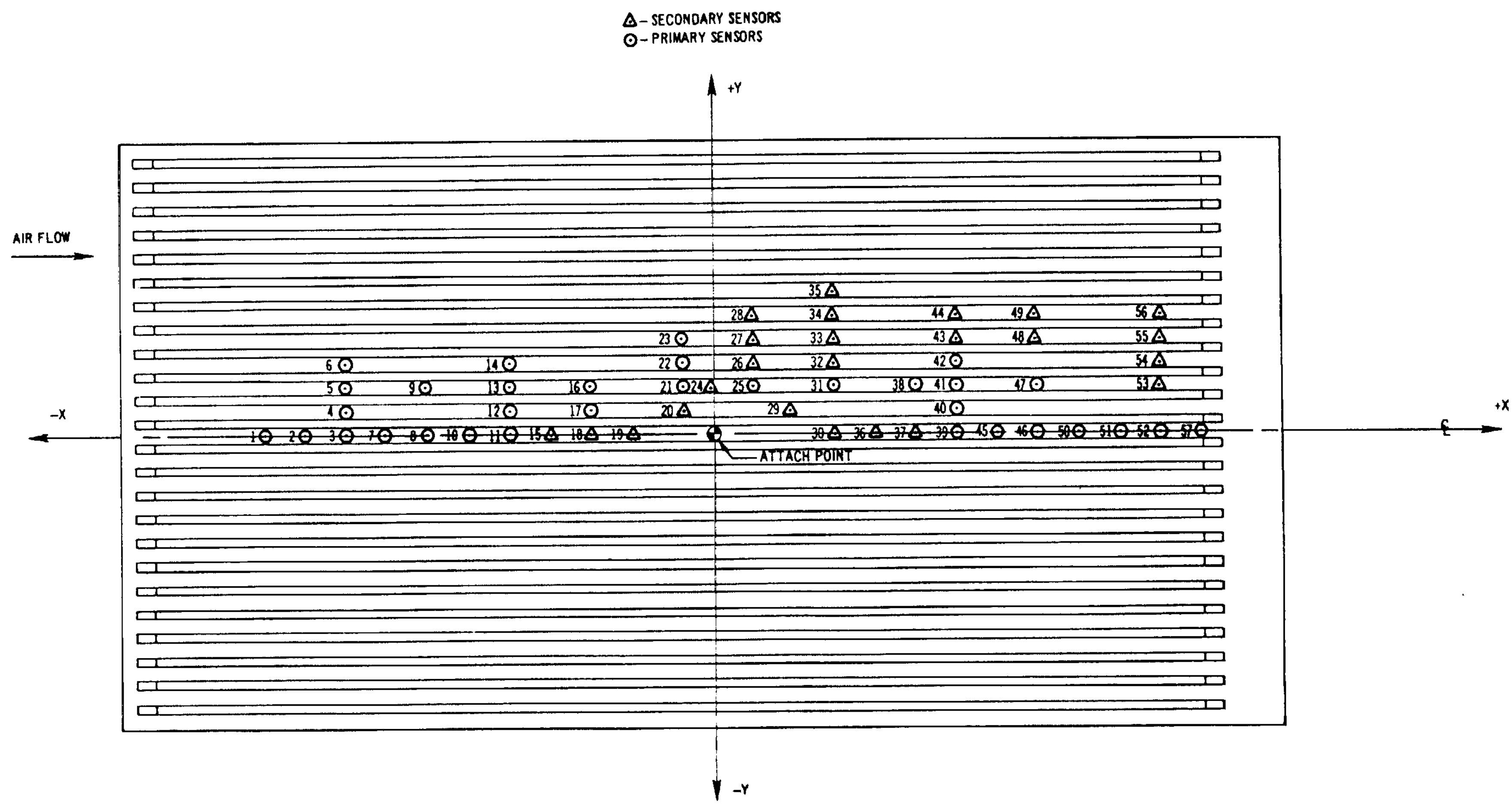


FIGURE 19

HEAT TRANSFER TEST PLATE WITHOUT STRINGERS
CORNELL SHOCK TUNNEL
TEMPERATURE GAGE LOCATION

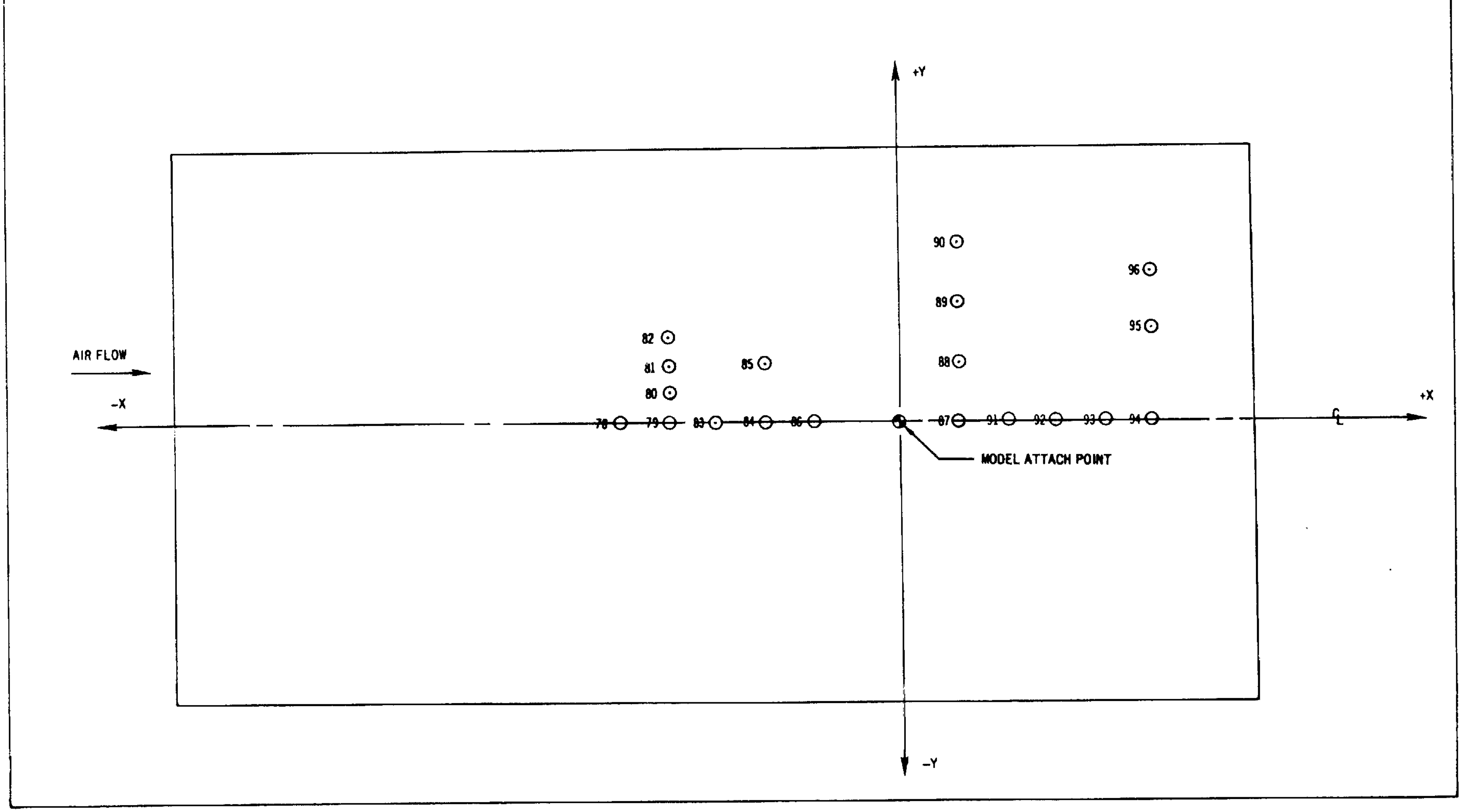
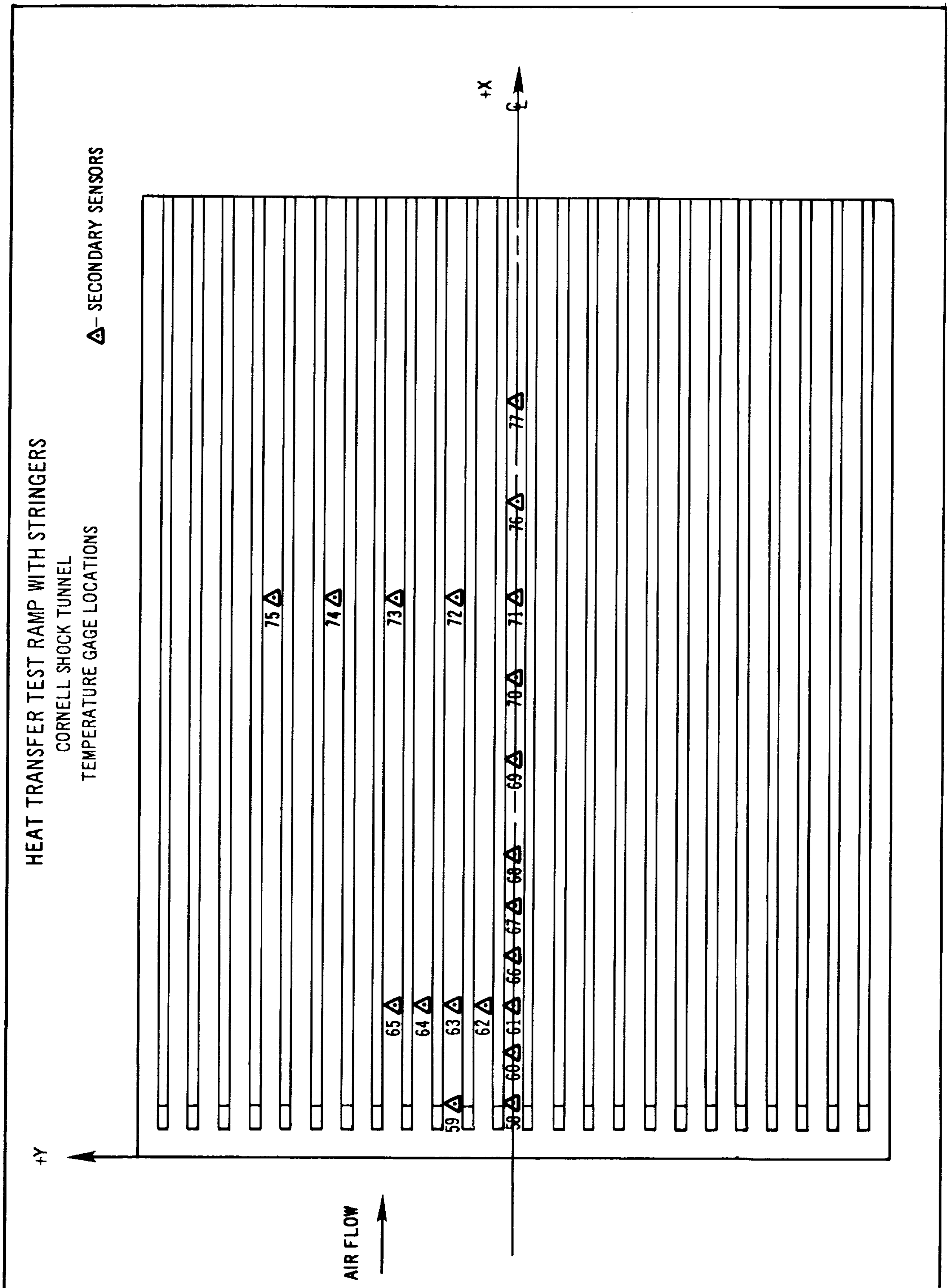


FIGURE 20



HEAT TRANSFER TEST RAMP WITH STRINGERS
CORNELL SHOCK TUNNEL
TEMPERATURE GAGE LOCATIONS
- SECONDARY SENSORS
+X
+Y
AIR FLOW
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77

FIGURE 21

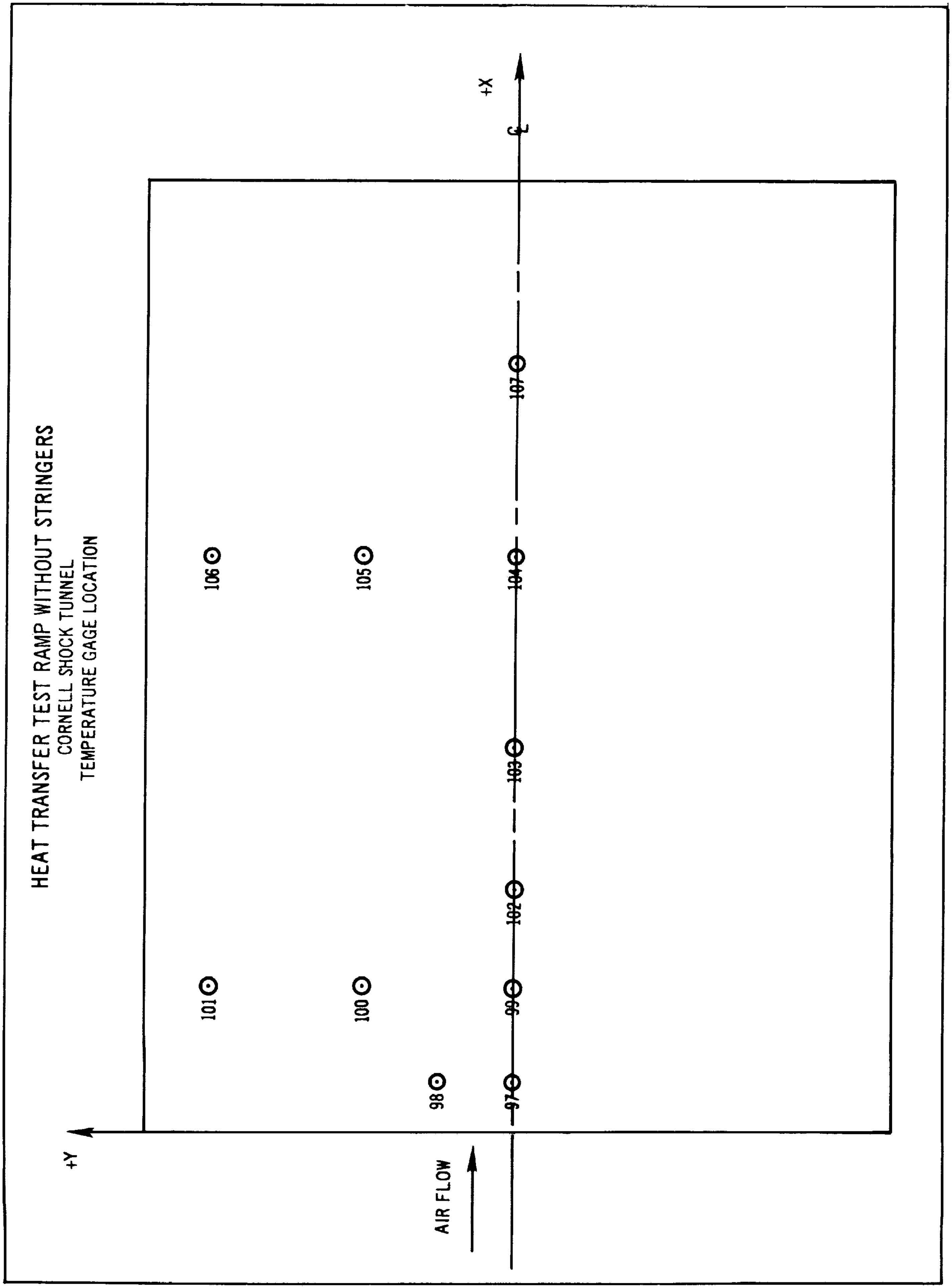

HEAT TRANSFER TEST RAMP WITHOUT STRINGERS
CORNELL SHOCK TUNNEL
TEMPERATURE GAGE LOCATION
+X
+Y
AIR FLOW
97
98
99
100
101
102
103
104
105
106
107

FIGURE 22

SM-46630

GENERAL PROTUBERANCE MODEL
CORNELL SHOCK TUNNEL
MODEL NO. 1
CALIBER = 1.5"

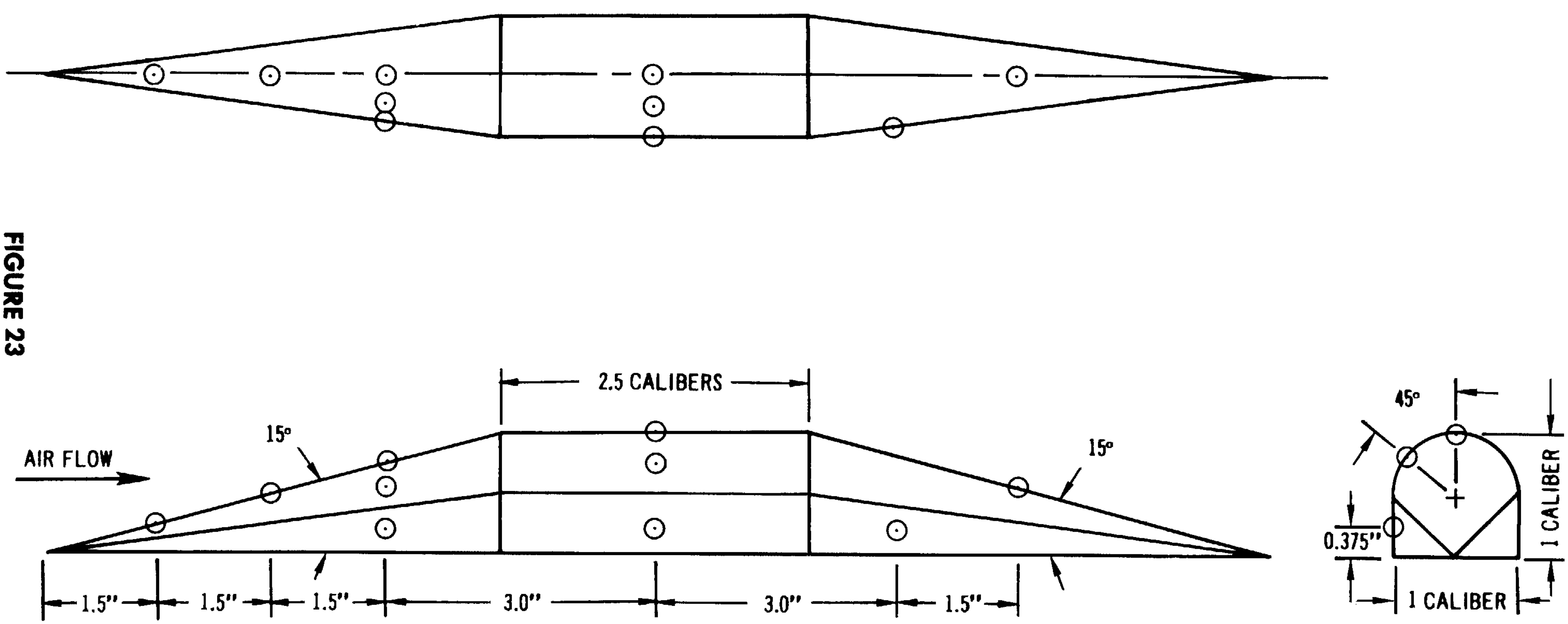


FIGURE 23

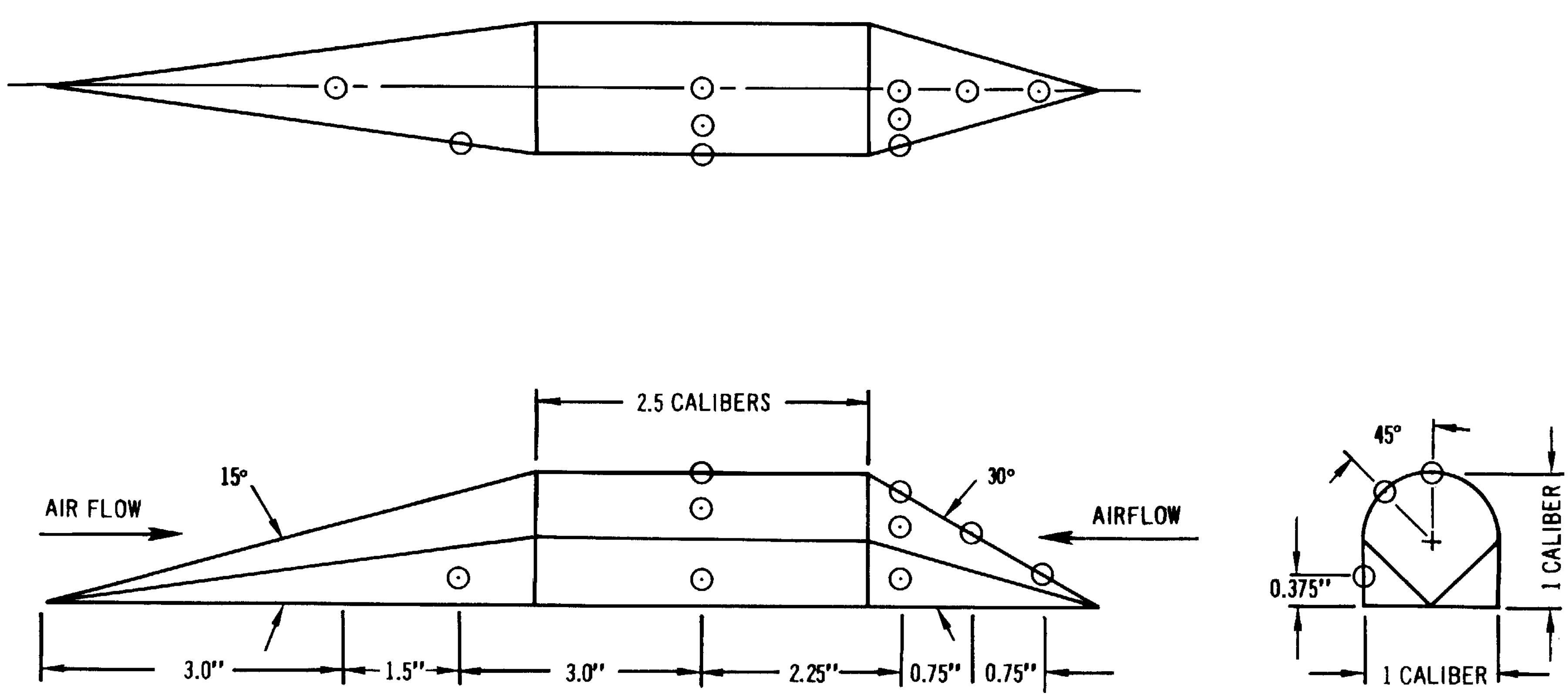
SM 46630

GENERAL PROTUBERANCE MODEL

CORNELL SHOCK TUNNEL

MODEL NO. 2*

CALIBER = 1.5"



* NOTE: THIS MODEL TO BE CAPABLE OF ATTACHMENT FOR AIR FLOW IN EITHER DIRECTION

FIGURE 24

SM 46630

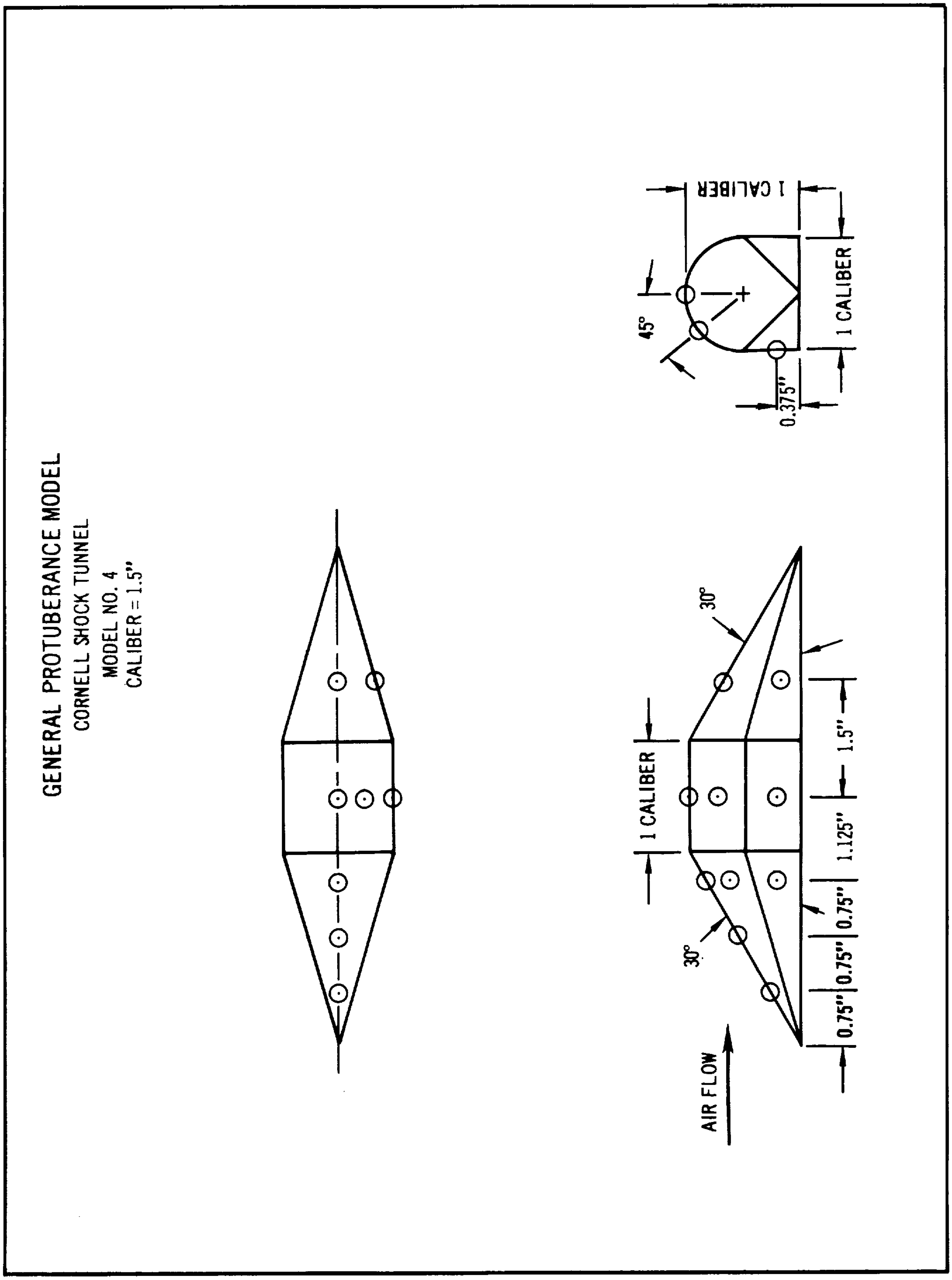


FIGURE 25

SM 46630

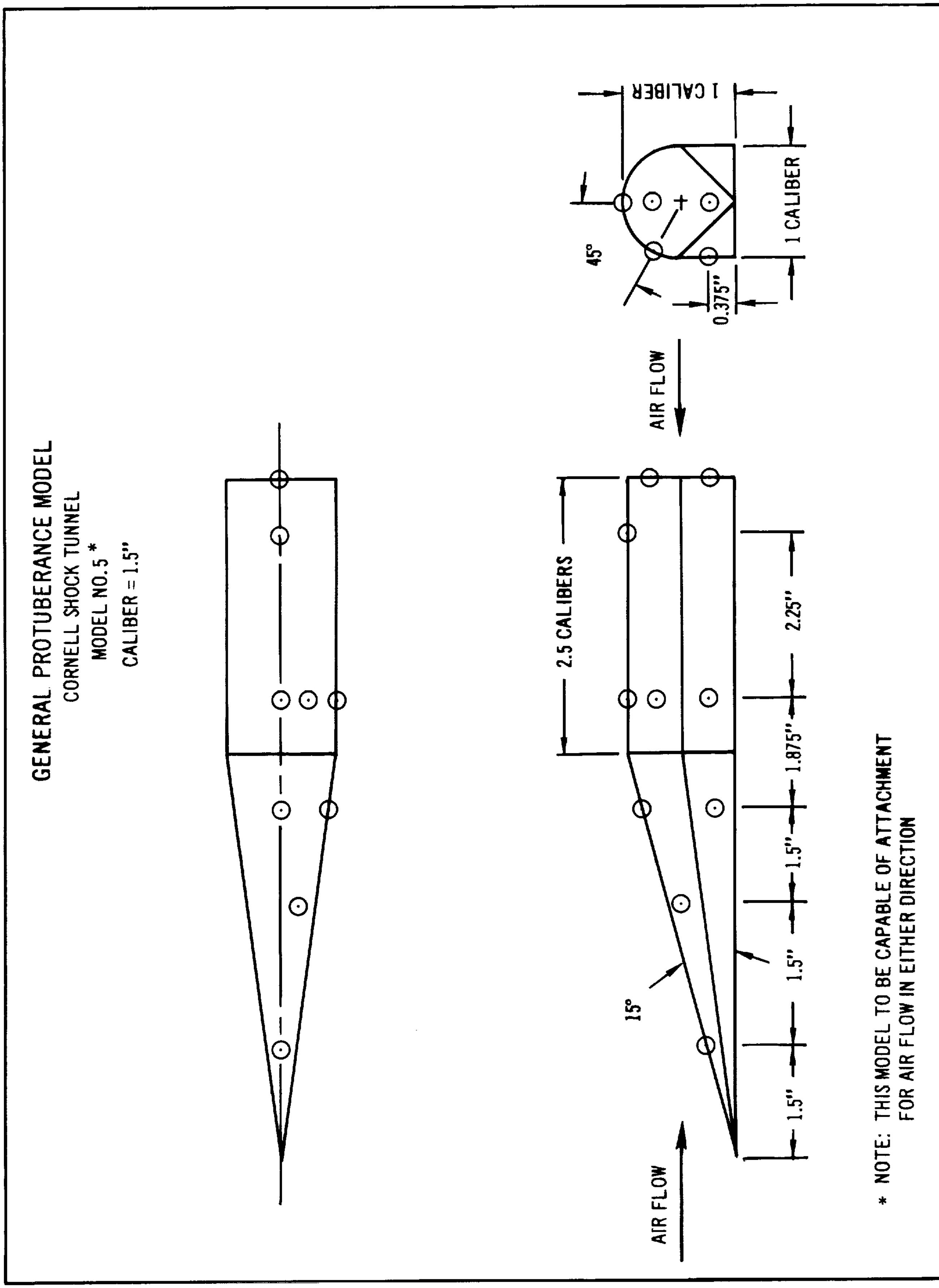


FIGURE 26

SM 46630

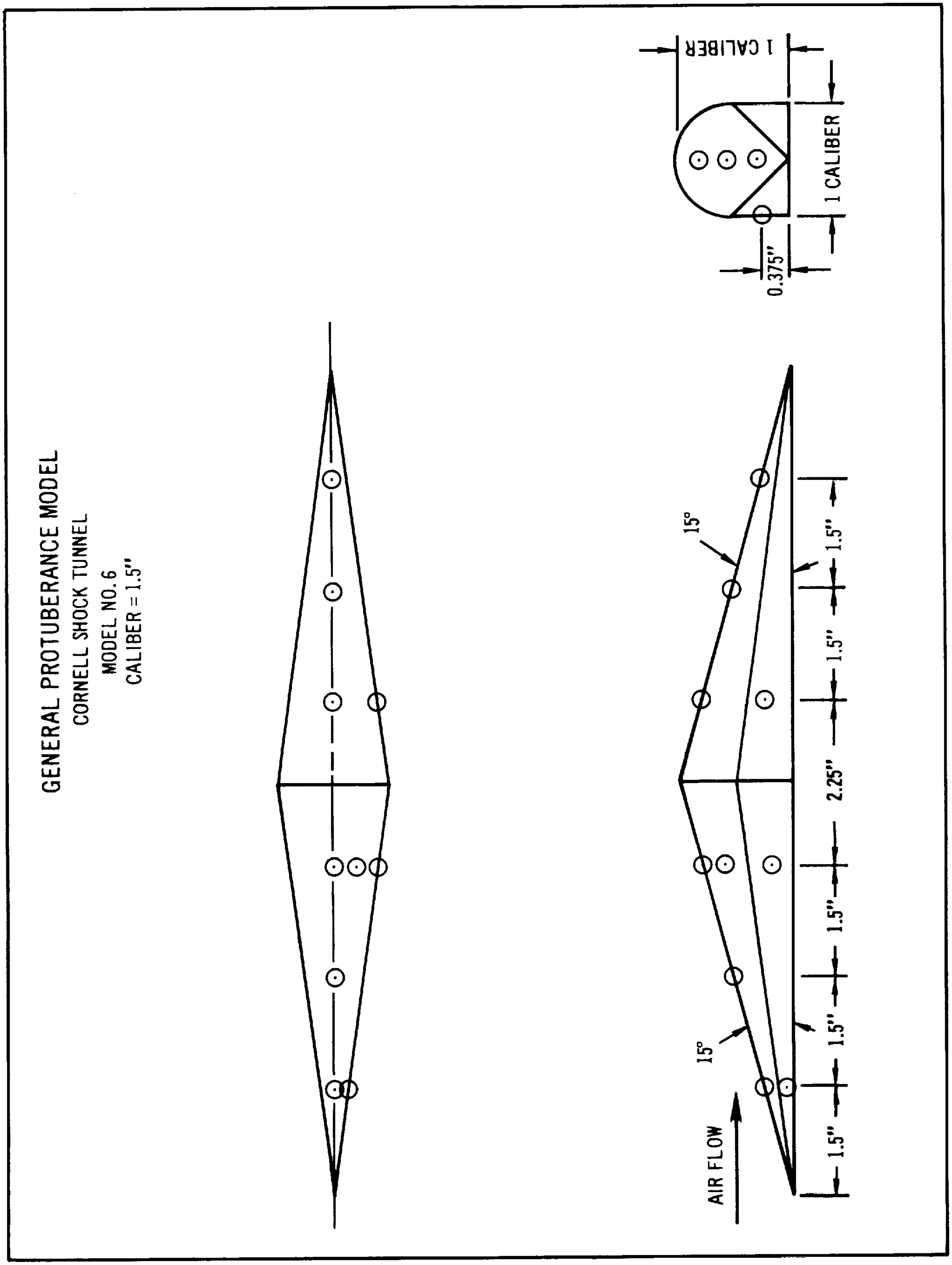


FIGURE 27

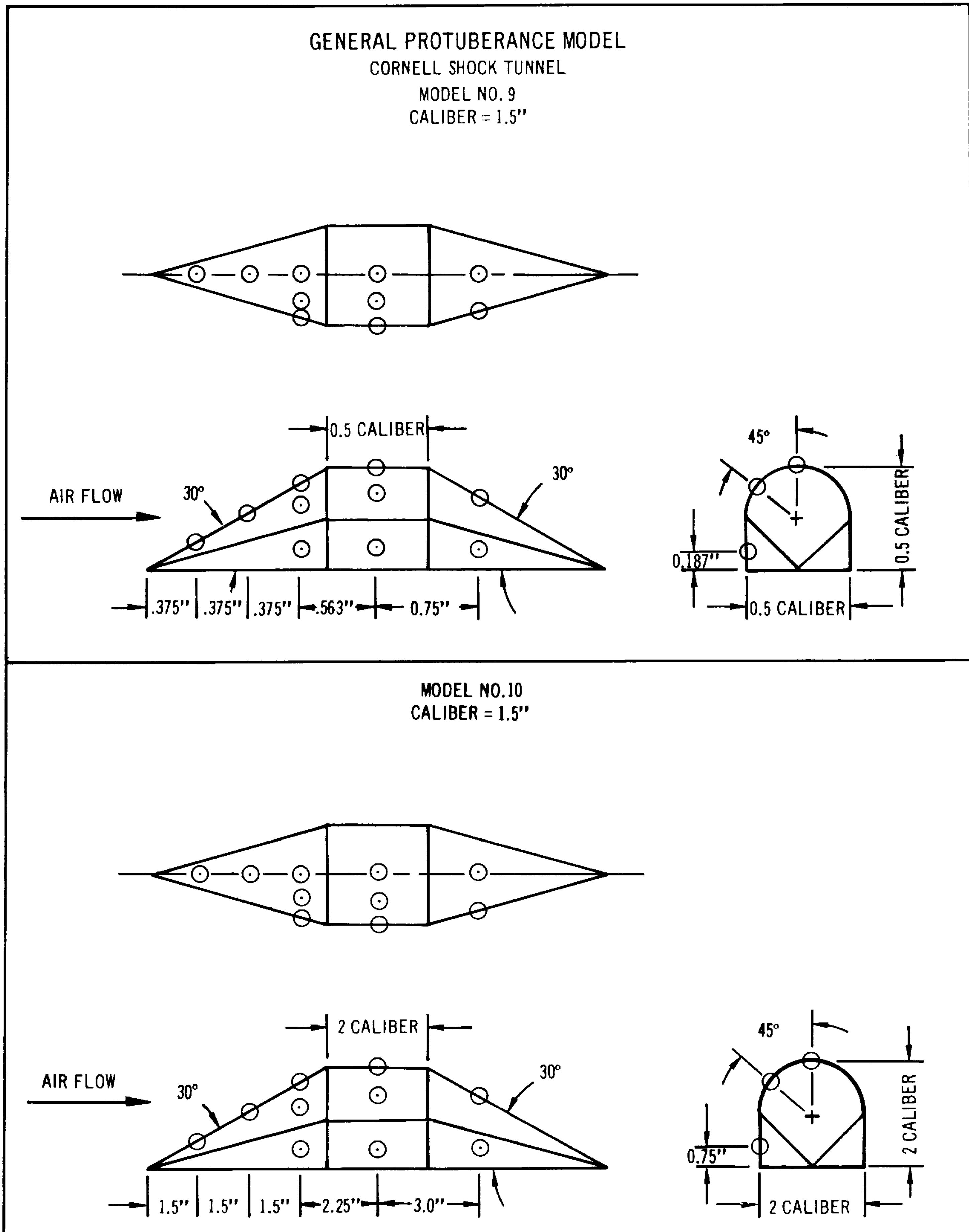


FIGURE 28

SM 46630

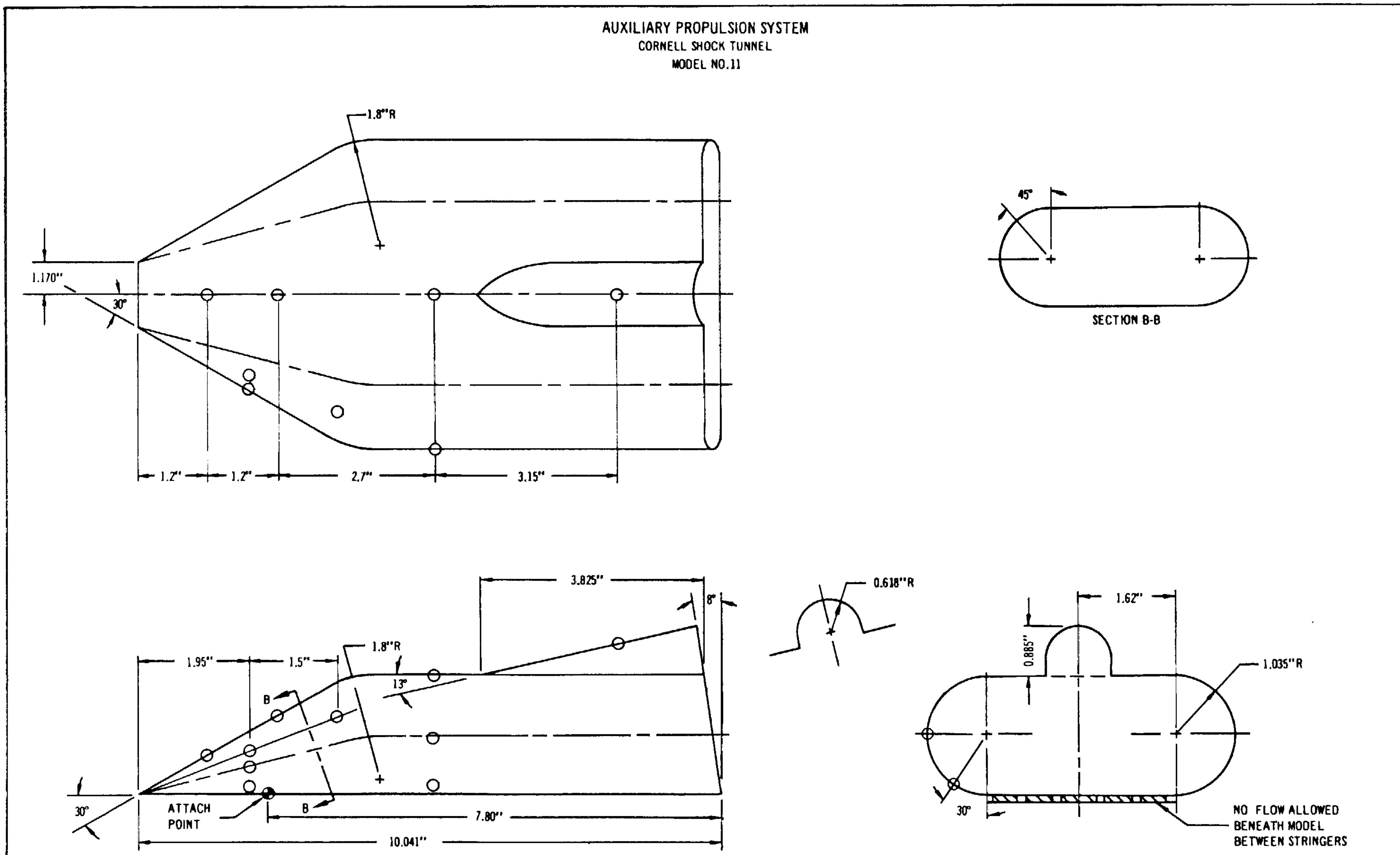

AUXILIARY PROPULSION SYSTEM
CORNELL SHOCK TUNNEL
MODEL NO.11
1.8"R
1.170"
30°
1.2"
1.2"
2.7"
3.15"
45°
SECTION B-B
3.825"
8°
1.95"
1.5"
1.8"R
13°
B
B
30°
ATTACH
POINT
7.80"
10.041"
0.618"R
1.62"
0.885"
1.035"R
30°
NO FLOW ALLOWED
BENEATH MODEL
BETWEEN STRINGERS

FIGURE 29

CIRCUMFERENTIAL RING LOCATION
CORNELL SHOCK TUNNEL
MODEL NO. 13

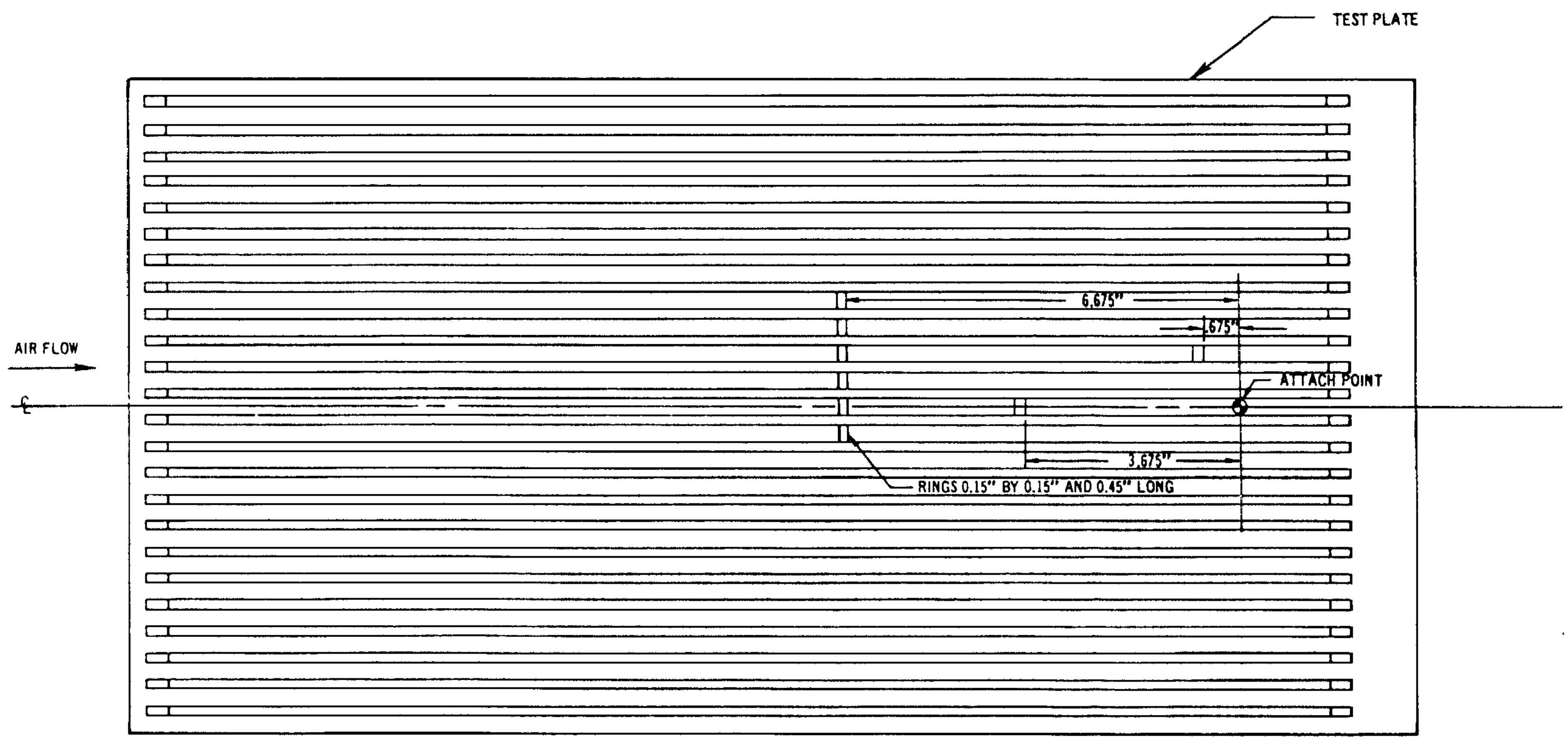


FIGURE 30